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Improving Healthcare Logistics Processes

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Improving healthcare logistics processes

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The line between disorder and order lies in logistics….

- Sun Tzu

PREFACE

This PhD thesis is a product of the PhD conducted by Diana Cordes Feibert at the Technical University of Denmark in collaboration with Herlev Hospital. The PhD commenced on 01 January 2014 and ended on 02 April 2017. This thesis is a continuation of the work conducted by Pelle Jørgensen and his thesis "Technology in Health Care Logistics" (Jørgensen, 2013).

This PhD thesis is article based, consisting of seven articles and a summary report of the methods, findings and conclusions. An overview of the journal papers and conference papers produced as part of the PhD project is provided in the following.

Journal papers:

P1	How to improve healthcare logistics processes - a systematic literature review
P2	Factors Impacting the Design of Healthcare Logistics Processes
P3	Measuring process performance within healthcare logistics - a decision tool for selecting track and trace technologies
P4	Benchmarking Healthcare Logistics Processes - A Comparative Case Study of Danish and US Hospitals

Conference papers:

P5	Relations between decision indicators for implementing technology in healthcare logistics - a bed logistics case study
P6	Measuring process performance within healthcare logistics - a decision tool for selecting measuring technologies
P7	Using the Analytic Network Process (ANP) to assess the distribution of pharmaceuticals in hospitals – a comparative case study of a Danish and American hospital

For the remainder of this thesis, the papers will be referred to as "P1" to "P7" as denoted in the lists above. The papers are listed according to the logical sequence of papers rather than in chronological order. For the journal papers, **P1** is in review for the special issue "Structured Literature Reviews and Meta Analyses in Supply Chain Management and Logistics" of the International Journal of Physical Distribution & Logistics Management. **P2** has been submitted to the International Journal of Logistics Management and is in review. **P3** has been published in a special issue by the Academy of Strategic Management Journal. **P4** has been published by the journal TQM & Business Excellence. All papers are appended at the end of this thesis with details of each paper.

Diana Cordes Feibert, Kgs. Lyngby, 02 April 2017

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Finally, to my friends and to my colleagues at DTU for making it an amazing three years and for your support through the ups and downs of the PhD roller-coaster ride.

SUMMARY

Healthcare costs are increasing due to an ageing population and more sophisticated technologies and treatments. At the same time, patients expect high quality care at an affordable cost. The healthcare industry has therefore experienced increasing pressures to reduce the cost of healthcare provision whilst providing high quality care. Logistics activities in hospitals provide a significant opportunity for cost containment in healthcare through the implementation of best practices.

Literature provides little guidance on how to improve healthcare logistics processes. This study investigates logistics processes in hospitals and aims to provide theoretically and empirically based evidence for improving these processes to both expand the knowledge base of healthcare logistics and provide a decision tool for hospital logistics managers to improve their processes.

Case studies were conducted at hospitals in Denmark and the US investigating three different types of processes: bed logistics, hospital cleaning, and pharmaceutical distribution. Based on an analysis and comparison of the case studies, a set of factors were identified influencing the decision on how to improve healthcare logistics processes. Furthermore, a method for benchmarking healthcare logistics processes was developed. Finally, a theoretically and empirically founded framework was developed to support managers in making an informed decision on how to improve healthcare logistics processes.

This study contributes to the limited literature concerned with the improvement of logistics processes in hospitals. Furthermore, the developed framework provides guidance for logistics managers in hospitals on how to improve their processes given the circumstances in which they operate.

DANSK SAMMENFATNING

Omkostningerne forbundet med at levere sundhedsydelser er stigende grundet en aldrende befolkning samt mere sofistikerede teknologier og behandlingsformer. Samtidig forventer patienter at modtage behandling af høj kvalitet til lavere omkostninger. Sundhedssektoren står derfor over for et stigende pres til at reducere omkostninger samtidig med forventningen om levering af behandlinger af høj kvalitet.

Forskning omkring forbedringen af logistiske processer på hospitaler er begrænset. Denne afhandling undersøger logistiske processer i sundhedssektoren og har til formål at tilvejebringe teoretisk og empirisk baseret evidens for hvordan logistiske processer på hospitaler kan og bør forbedres. Dermed bidrages både til udvidelsen af teoretisk viden inden for sundhedslogistik og til understøttelsen af beslutningstagere ved at udvikle et beslutningsværktøj til forbedringen af logistiske processer på hospitaler.

Case studier blev udført på hospitaler i Danmark og USA, hvor tre forskellige typer processer blev undersøgt: sengelogistik, hospitalsrengøring og distribution af medicin. Baseret på en analyse og sammenligning af case studierne blev beslutningsfaktorer identificeret i forhold til forbedringen af logistiske processer på hospitaler. Ydermere blev en metode udviklet til benchmarking af logistiske processer i sundhedssektoren. Slutteligt blev et teoretisk og empirisk funderet framework udviklet til at hjælpe beslutningstagere i sundhedssektoren med at træffe en beslutning omkring forbedringen af logistiske processer på hospitaler.

Dette studie bidrager til den begrænsede litteratur, der findes omkring forbedringen af logistiske processer på hospitaler. Derudover blev et framework udviklet til at guide beslutningstagere på hospitaler omkring forbedringen af deres logistiske processer i forhold til de omstændigheder, der gør sig gældende for det pågældende hospital.

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List of abbreviations and acronyms

AGV	Automated guided vehicle
AHP	Analytic hierarchy process
ANP	Analytic network process
ASR	Automated storage and retrieval
AT	Automated transport
BC	Barcode
BPM	Business process management
BPR	Business process reengineering
CPFR	Collaboration, planning, forecasting and replenishment
DK	Denmark
ED	Emergency department
EDI	Electronic data interchange
FDA	United States Food and Drug Administration
HRM	Human resource management
ICT	Information and communication technology
IT	Information technology
JIT	Just-in-time
LRQ	Literature review question
RFID	Radio frequency identification
RP	Replenishment policy
OECD	Organisation for Economic Co-operation and Development
OM	Operations management
RQ	Research question
SC	Supply chain
SCM	Supply chain management
SD	Single dose systems
SLS	Stockless systems
SOP	Standard operating procedure
TCO	Total cost of ownership
TQM	Total quality management

UK	United Kingdom
US	United States of America
VMI	Vendor managed inventory
μ	Average
σ	Standard deviation

1 INTRODUCTION

This chapter provides the background and motivation for this study. A justification of the research questions investigated in this study is provided from a practical and scientific point of view. Furthermore, key terms used throughout this thesis are defined, and finally the structure of the thesis is presented.

1.1 BACKGROUND

Healthcare costs have been rising due to ageing populations and more sophisticated treatments. At the same time, patients expect high quality care at lower costs (Abel-smith and Mossialos, 1994; OECD, 2015; Saltman and Figueras, 1997; WHO, 2010). Cost containment in healthcare has therefore become a major issue for hospitals. The 2017 OECD report *Tackling Wasteful Spending on Health* found that a significant share of health spending in OECD countries is ineffective and even wasteful (OECD, 2017). In this context, "wasteful" is understood as either 1) services or processes that are harmful or do not deliver benefits or 2) costs that could be avoided by substituting with cheaper alternatives with identical or better benefits. Recommendations in the OECD report to reduce wasteful spending include better use of information and direct interventions to prompt organizational change and coordination between healthcare providers. To reduce wasteful spending, hospitals have turned to interventions originating from the manufacturing industry, e.g. lean (Radnor et al., 2012; Souza, 2009), six sigma (Lifvergren et al., 2010; Taner et al., 2007), total quality management (TQM) (Smith and Offodile, 2008; Yasin et al., 2002) and business process reengineering (BPR) (Bertolini et al., 2011; Yasin et al., 2002).

Kaplan and Porter argue that *to solve the cost crisis in healthcare*, the cost of providing healthcare must be understood. In turn, to understand the cost of providing healthcare, it is necessary to understand the processes (Kaplan and Porter, 2011). More than 30 per cent of hospital expenditure relates to logistics processes (Aptel et al., 2009; McKone-Sweet et al., 2005; Poulin, 2003). According to Poulin (2003), the implementation of best practices could eliminate half of the costs related to logistics activities in hospitals.

The need for the effective flow of materials and information has been evident throughout history; e.g. in building major constructions such as the pyramids, in the battlefield, and in providing humanitarian aid (Christopher, 2011; Lummus et al., 2001). Modern logistics came of age during World War II (Brewster, 2008), and has since been adopted by businesses to gain competitive advantage (Christopher, 2011; Rutner et al., 2012). According to Rutner and Langley Jr, the value of logistics lies in “meeting customer service requirements while minimizing supply chain costs and maximizing partners’ profits” (Rutner and Langley Jr, 2000). Logistics can therefore help reduce costs in the supply chain (SC).

Logistics and supply chain management (SCM) are two related concepts. The Council of Supply Chain Management Professionals defines logistics management as follows:

> Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements. (Council of Supply Chain Management Professionals, 2016)

This definition of logistics management indicates that logistics is part of SCM. The SCM framework developed by Cooper et al. consists of three components: business processes, management components and supply chain structure (Cooper et al., 1997). From an SC perspective, manufacturing and service industries have more similarities than dissimilarities (Aitken et al., 2016). Spens and Bask therefore extend the application of the SCM framework to a healthcare setting (Spens and Bask, 2002). Although SCM concepts are applicable for a healthcare setting (Meijboom et al., 2011), SCM and logistics concepts have relatively small or no presence in healthcare (Towill and Christopher, 2005). Furthermore, the goals of applying management approaches to improve healthcare logistics processes are often not reached. Managers are therefore left to their own experience and judgment in deciding how to improve healthcare logistics processes (van Lent et al., 2012). This study therefore investigates how to improve healthcare logistics processes in hospitals. Healthcare logistics processes are examined for two country settings: Denmark and the US.

1.2 HEALTHCARE

This study investigates logistics processes in a Danish and a US context. The two healthcare systems are distinctly different. The provision of healthcare services and the difference between Danish and US healthcare systems are briefly described in this section.

1.2.1 THE PROVISION OF HEALTHCARE SERVICES

The provision of healthcare services is important for the wellbeing and prosperity of any society. The Oxford dictionary defines healthcare as "the maintenance and improvement of physical and mental health, especially through the provision of medical services". Healthcare systems provide healthcare services and can be divided into three main categories: 1) the national health service (NHS) or Beveridge model, 2) the social security or Bismarck model and 3) private insurance. The NHS model is found in countries such as the UK, Italy, Spain, Canada and the Nordic countries. The social security model is found in countries like Germany, Austria, France, Benelux, Switzerland and Japan. The private insurance model is found in the US (Elola, 1996; Lameire et al., 1999). These models are those predominantly used in the listed countries, but the different systems do co-exist within country borders. NHS systems and social security systems are publicly funded and health insurance is publicly provided. The provision of healthcare in NHS systems is public, whereas in the social security system the providers are either private or public. In a private system, funding, insurance and provision are all private (Elola, 1996; Lameire et al., 1999).

The problems experienced in a hospital depend highly on the type of health system adopted in that country (Elola, 1996). The findings by Elola suggest that NHS countries are better at cost containment and tend to be more efficient, but experience lower levels of public satisfaction, whereas social security systems experience higher public satisfaction but poor cost control. Thus, there seems to be a trade-off between cost control/efficiency and public satisfaction. Elola argues that overcoming this trade-off has been the main goal of reforms in Western European countries.

From the 1980's, a wave of healthcare reforms swept across Europe. These reforms were mainly rooted in the public debate pressuring for increased efficiency, effectiveness, patient choice and patient influence regarding the provision of healthcare (Saltman and Figueras, 1998). According to Donabedian, inefficiency from a healthcare perspective is the extent to which improved health is achieved in an unnecessarily costly way (Donabedian, 1988). Donabedian assesses quality of care in terms of *structure*, *process* and *outcome*. *Structure* is the setting in which care occurs, i.e. materials, human resources and organizational structure. *Process* denotes activities carried out to give and receive care. *Outcome* is the effect of care on the health status of a patient. Quality assessment should include the assessment of all three elements.

One approach to assessing the quality of care is to study the setting in which care provision takes place. This could be viewed as an assessment of the *structure* and could include administrative and related processes supporting the provision of care (Donabedian, 2005). Supporting processes therefore contribute to the quality of care and should be assessed as part of care assessment. Longo and Masella distinguish between four types of processes in hospitals: 1) core processes, 2) support processes, 3) network processes, and 4) management processes (Longo and Masella, 2002). In this study, the supporting processes related to logistics activities in hospitals are investigated.

1.2.2 The healthcare industry in Denmark

Part of this study focuses on hospitals located within the capital region of Denmark. Healthcare in Denmark is mainly publicly funded. The Danish health system is similar to that found in the other Nordic countries, providing universal healthcare (Elola, 1996). As a response to a growing critique of inefficiencies in the public sector, reforms have taken place in Denmark since the 1970's, similar to those experienced in other Western European countries (Andersen and Jensen, 2010). The Danish healthcare system has been politically, financially and operationally decentralized (Pedersen et al., 2005), and a further expansion of the existing decentralization took place in the Danish public sector. Furthermore, a re-centralization and a move toward marketization occurred. In 1993, a reform allowed for patients' free choice of hospital, including the choice of private and foreign hospitals (Andersen and Jensen, 2010). In 2007, a reform of the Danish public sector was introduced, reducing the number of municipalities from 271 to 98 and in addition introducing five regions, each of which covers several municipalities. The main responsibility of the regions is the administration of hospitals (KL, 2007). Hence, the Danish health system was reformed as part of this extensive local government reform (Andersen and Jensen, 2010).

Two regions in the Eastern part of Denmark have joined forces to create a digital platform for patients in those two regions, i.e. the capital region and the Zealand region. The digital platform, also known as *Sundhedsplatformen* or *the health platform*, has been developed by the American software provider Epic (Region Hovedstaden, n.d.). The goal of the digital platform is to ensure more coherent treatment and to increase patient safety, particularly when treatment occurs across different departments and hospitals. The digital platform allows for easier communication between the patient and the hospital and for sharing information between involved health providers. The goal of introducing a new digital platform is to improve health services delivered to patients, to create coherent patient treatment, and to increase patient safety. The implementation of the system also improves the procedures of the hospitals involved (Region Hovedstaden and Region Sjælland, n.d.). The health platform is therefore an example of how a technological intervention has been implemented to enable process improvements in the Danish healthcare system.

Expenditure growth in the Danish health system has been low and controlled (Pedersen et al., 2005). The hospital regions have been expected to deliver a yearly productivity increase of 2% in terms of providing more treatment at a budget standstill. This year on year productivity increase has been criticized by the leaders of the hospital regions (Astman et al., 2016). One way to reduce the cost of healthcare provision without increasing the pressure on care personnel would be to reduce the cost of logistics services provided in hospitals.

The Danish healthcare system is currently spending approximately 40 billion DKK on the construction of new hospital buildings over a 10-15 year timespan. The goals of this massive undertaking of constructing new hospital buildings are to ensure a better and more cohesive patient treatment, to improve patient safety, increase efficiency and provide higher quality services. Health services are, therefore, pooled in fewer hospitals to increase resource utilization, creating more specialized hospitals and increasing quality of care. The new buildings can better support these goals and the pooling of functions (Danske Regioner, 2013). The current construction of hospital buildings makes hospital logistics a highly relevant topic both in terms of how to design logistics processes as a consequence of the new buildings and in terms of how the buildings can support improved logistics processes.

1.2.3 THE HEALTHCARE INDUSTRY IN THE US

Healthcare provision in the US is mainly covered by Medicare, Medicaid or private insurance (Lameire et al., 1999). In addition, a significant share of the US population is uninsured and will have to pay healthcare services as an out-of-pocket expense. According to Gallup, 10.9 per cent of adults in the US did not have health insurance as of the third quarter of 2016. Since the Patient Protection and Affordable Care Act (ACA) requirement that Americans carry health insurance took effect in 2014, the rate of uninsured has declined from 17.1 per cent to 10.9 per cent (Gallup, n.d.).

Medicare is a federal insurance program for American citizens aged 65 years or older and certain other patient groups (medicare.gov, n.d.). The insurance program is funded through the Hospital Insurance Trust Fund and the Supplementary Medical Insurance Trust Fund (medicare.gov, n.d.). Medicare was signed into law in 1965 alongside the other government funded health insurance program Medicaid. Medicaid is a social healthcare program providing healthcare coverage for low-income citizens (medicaid.gov, n.d.).

In March 2010, the ACA was signed into law, reforming the US healthcare system with the aim to expand healthcare coverage, ensure accountability for insurance companies, ensure lower healthcare costs, increase the choice of the patient, and enhance the quality of care (medicaid.gov, n.d.). Most recently, the ACA has received significant media attention due to the attempt to repeal and replace the Act.

The private insurance model used in the US to fund healthcare services also results in the highest cost of care compared to other healthcare models (Lameire et al., 1999). Healthcare expenditure per capita and as a percentage of GDP in the US far exceeds that of any other country (OECD, 2016a, 2016b). The ACA promotes the reduction of healthcare costs. This study investigates how healthcare logistics processes can be improved and consequently contribute to lowering those costs.

1.3 Logistics in Healthcare

Logistics departments in hospitals are responsible for an array of supporting flows including bed logistics (Schmidt et al., 2013; Utley et al., 2003), drug distribution (Mustaffa and Potter, 2009; Romero and Lefebvre, 2015), managing the blood SC (Spens and Bask, 2002), sample transport (Al-Riyami et al., 2014; Jørgensen et al., 2013), patient transport (Longo and Masella, 2002), cleaning (Longo and Masella, 2002), laundry services (Aptel and Pourjalali, 2001; Longo and Masella, 2002), food distribution (Aptel and Pourjalali, 2001; Granlund and Wiktorsson, 2013), managing surgical tools (Fredendall et al., 2009; Longo and Masella, 2002), managing medical aids (Longo and Masella, 2002), waste management (Granlund and Wiktorsson, 2013), and mail services (Granlund and Wiktorsson, 2013). This list of processes is not exhaustive but exemplifies the diversity of activities undertaken by logistics departments in hospitals. These processes are embedded in complex healthcare settings characterized by unique and interrelated processes encompassing several organizational units. In addition, processes within a healthcare environment tend to be unpredictable (Aronsson et al., 2011; Kannampallil et al., 2011; Lillrank et al., 2011), and problems are often specific to the healthcare context. This healthcare specificity makes it challenging to standardize processes (Helfert, 2009). A process oriented approach in healthcare can therefore be difficult (Aronsson et al., 2011; Jarrett, 1998; Lillrank et al., 2011).

An article dating back to 1937 from The American Journal of Nursing titled *Hospital Housekeeping and Management: A List of Free and Inexpensive Materials* was identified ("Hospital Housekeeping and Management", 1937), indicating some relevance to materials management and purchasing in hospitals. However, most of the literature relating to healthcare logistics emerged in the 1990's with the introduction of just-in-time (JIT) and stockless systems in a hospital setting. Previous literature is scarce and the titles mainly relate to materials management in hospitals and procurement to some extent. The 1993 paper by Kim and Schniederjans (1993) compares JIT and stockless systems and the later well-cited paper by Jarrett titled *Logistics in the health care industry* discusses the suitability of JIT in a healthcare setting (Jarrett, 1998). However, the pool of literature concerned with the improvement of logistical flows in hospitals is limited. Yet, instances of interventions to improve healthcare logistics processes have been reported. Literature provides examples of process improvement approaches applied in healthcare logistics, including BPR (Kumar et al., 2008) and benchmarking, e.g. (Aptel and Pourjalali, 2001; Böhme et al., 2013, 2016). Furthermore, technologies can enable process reengineering and process innovation (Davenport, 1993; Hammer and Champy, 1993). Two types of technologies have received particular attention, namely radio frequency identification (RFID) and barcodes, e.g. (Anand and Wamba, 2013; Chircu et al., 2014; Romero and Lefebvre, 2015; Yao et al., 2012). These technologies can enable the flow of information and track items in the SC. Another important aspect of healthcare logistics is managing inventories. Hospitals have adopted stockless and JIT strategies to reduce inventory levels and inventory costs, e.g. (Heinbuch, 1995; Kim and Schniederjans, 1993). Other strong enablers of process change are organizational structure and human resources (Davenport, 1993). To gain the full potential of logistics benefits, the importance of logistics must be acknowledged in the organization (Ralston et al., 2013). It is therefore important to align incentives in the organization to ensure that the entire organization works to achieve the same goals.

When decision makers decide to make changes to a process, they must consider how a change affects other parts of the system:

> Reengineering a company's business processes changes practically everything about the company, because all these aspects – people, jobs, managers and values – are linked together. (Hammer and Champy, 1993)(p.80)

I.e. making changes in a healthcare system will have implications for other parts of the system. This study considers the interrelations between different aspects of a healthcare logistics system when implementing interventions for process improvement purposes. The study draws on literature from BPM, logistics and SCM, technological assessment and justification, and organizational management, mainly within the confines of a healthcare logistics setting. In the periphery of the theoretical landscape of this study lie healthcare management, performance management and measurement in healthcare, healthcare benchmarking, health technology assessment, planning and scheduling in healthcare, lean in healthcare, and quality assessment in healthcare. However, these streams of literature are not included in the scope of this thesis. Thus, the application of operations management (OM) and SCM concepts to improve healthcare operations in general is not in scope; only the logistics processes within hospitals are considered, e.g. as the processes listed in the beginning of this section.

1.4 Problem statement

Logistics activities in hospitals provide significant opportunities for improvement and cost containment in healthcare. However, literature provides little guidance on how to improve healthcare logistics processes. This study aims to provide theoretically and empirically based evidence for improving logistics processes in hospitals to both expand the knowledge base of healthcare logistics and to provide a decision tool for managers with which to improve healthcare logistics processes. The overall research question (RQ) investigated in this study is therefore formulated as the following meta-RQ:

> **Meta-RQ**: How can hospitals improve their logistical processes to ensure that the process design and performance fit the needs and preferences of a hospital?

Hospitals may have different needs and preferences in terms of a logistics solution depending on the circumstances in which a hospital operates, the strategy of the hospital, and other contingent factors. The "needs and preferences" are therefore included in the meta-RQ.

To answer the meta-RQ, three RQs have been formulated. To improve and design a new process, it is important to understand the existing process (Davenport, 1993). Healthcare logistics processes must therefore first be characterized to understand the unit of analysis, its inherent challenges and its composite elements. Hence, the first RQ is as follows:

> **RQ1**: How can healthcare logistics processes be characterized in terms of challenges and composite design elements?

The composite design elements relate to the different types of interventions which have been implemented to design and improve a process. One of the issues for managers in improving healthcare logistics processes is to know how best to improve their processes. Instead of making a decision based purely on experience and judgment (van Lent et al., 2012), managers should be able to make an informed decision about the best way to improve their processes under the given circumstances. To enable managers to make an informed decision, they must become aware of the aspects to consider in making a decision to improve a healthcare logistics process, i.e. the factors impacting the decision. The second RQ is therefore:

> **RQ2**: Which factors should decision makers consider when improving healthcare logistics processes?

Once it is clear which aspects should be considered in a decision process, the next step is to determine which solution is the best alternative for a manager to implement, leading to the third RQ:

> **RQ3**: How can the identified impact factors be used to assess healthcare logistics systems?

Case studies are conducted at hospitals located in Denmark and the US to answer the investigated RQs. Furthermore, this study focuses on the logistics activities found within the boundaries of a hospital. A framework has been developed as part of this study to provide a decision tool enabling managers to make an informed decision on improving healthcare logistics processes.

1.5 DEFINING KEY TERMS

Definitions of key terms as they are understood in this study are provided in the following. A discussion of alternative definitions of the terms defined here will not be provided. The objective of this section is to clarify how a set of key terms are defined for the purpose of this thesis.

A *process* is defined according to the definition by Lillrank et al. in which a process exhibits the following characteristics (Lillrank et al., 2011):

1) employs a dedicated set of resources used to transform input to output for the benefit of an internal/external customer

2) is an ordered flow with beginning and end and consists of two or more process steps that use different resources, skills or equipment

3) the result can be defined and flow planned before production

4) a process can be repeated

A *procedure* relates to the process concept and is a description of how a particular process should be carried out.

Process design refers to the constituent elements of a process, including process steps, logistics and SCM aspects characterizing the process, implemented technologies, and the organizational structure supporting the activities carried out in the process. A more elaborate justification of these four elements describing the design of a process is provided in the literature review (P1).

Business process management (BPM) is defined here as a structured approach to analyze and continually improve fundamental activities of an organization's operations. This definition is an adaption of the definition provided by Zairi (Zairi, 1997).

A *supply chain* is "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" (Mentzer et al., 2001).

Supply chain management (SCM) can be defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (Mentzer et al., 2001).

Logistics is “that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements” (Council of Supply Chain Management Professionals, 2016).

Healthcare logistics refers to logistics activities provided in a healthcare setting.

A *healthcare logistics process* is a process embedded in a healthcare logistics setting.

A *healthcare logistics system* refers to a group of interrelated elements related to healthcare logistics activities, forming a whole.

Healthcare benchmarking is defined as “a continuous, systematic process of measuring products, services and practices against organizations regarded to be superior with the aim of rectifying any performance ‘gaps’“ (Kouzmin et al., 1999).

Structure as in *organizational structure* describes how the organizational units interrelate, the human resources associated with each organizational unit and the roles and responsibilities of the organizational units and the associated human resources.

A *technology* refers to machinery, equipment, devices or systems developed from scientific knowledge.

A *challenge* is a problem or issue faced by an individual or organization and poses an obstacle to achieving a goal.

An *intervention* is the act of making a change to the current state of things by restructuring or inserting physical or intangible elements of/to a system.

An *improvement* refers to the transformation of making something better. In this study, improvements are not limited to a special type of improvement such as cost or quality improvements, but something which is perceived as better compared to the previous state of things. However, the types of improvement of particular interest in this study are those considered to be improvements by decision makers and employees involved in healthcare logistics processes.

A *benefit* is an advantage gained from something, e.g. an intervention.

Quality is defined in relation to logistics and encompasses total support of customer needs, timely delivery, and error free transactions. This definition is based on the findings by Sohal et al. who investigate quality in logistics for North American, European and Australian companies (Sohal et al., 1999). This is in accordance with Callender and Grasman, who state that the main purpose of the healthcare SC is to deliver products in a timely manner to fulfil the needs of providers (Callender and Grasman, 2010).

1.6 Structure of the thesis

The thesis is structured as follows. After the introduction, a literature review is provided, which enfolds literature pertaining to the improvement of healthcare logistics processes. A methodology section follows, describing the philosophical position and scientific methods adopted for this study. Subsequently, the results are presented, followed by a chapter consolidating the final developed framework. The results are then discussed and the research questions answered. A concluding chapter summarizes the findings of this thesis and offers suggestions for future research. Reflections on the research process and findings of this research project are provided in the final chapter. Each chapter begins with a short introduction delineating the content and structure of the chapter and is concluded with a chapter summary. Additional material substantiating the findings of this research is found in the Appendix and referred to in the thesis. Furthermore, the papers produced as part of this PhD are appended at the end of the thesis.

2 LITERATURE REVIEW

This literature review is based on the article *How to improve healthcare logistics processes - a systematic literature review* (P1). Key findings from P1 together with additional findings of the literature review not reported in the paper will be described in this chapter. The literature review aims to enfold existing literature concerning how to improve healthcare logistics processes. This study therefore examines the interventions that decision makers can apply to improve healthcare logistics processes and determines under which circumstances different interventions are recommendable. A systematic literature review method is applied to answer four review questions, two of which were reported in P1.

The chapter is structured as follows. First, the review questions are presented. The relation between review questions and research questions can be found in the Methodology. Second, the applied systematic review method is described. Third, the results of the literature review are presented in both a descriptive and thematic analysis. Fourth, based on the findings from the literature review, a framework for selecting interventions to improve healthcare logistics processes is developed. Fifth, the limitations of the literature review and developed framework are stated. Sixth, the contributions of this study to literature and the theoretical foundation of the thesis are described. Finally, a brief chapter summary concludes the chapter.

2.1 LITERATURE REVIEW QUESTIONS

The literature review examines the following review questions:

LRQ I. What are the challenges specific to healthcare logistics processes?

LRQ II. What does existing literature offer in terms of how to improve healthcare logistics processes?

LRQ III. What are the contingent factors that determine when different interventions and approaches for improving healthcare logistics processes are recommendable?

LRQ IV. Which benefits can interventions and approaches within healthcare logistics realize?

P1 examines LRQ II and LRQ III. The findings regarding LRQ II and LRQ III will therefore only be briefly summarized in the thesis. LRQ I and LRQ IV will be treated in more detail and investigated in the thesis.

2.2 THE SYSTEMATIC REVIEW METHOD

The systematic review method is rooted in the medical science field and ensures a rigorous and transparent review process (Tranfield et al., 2003). The systematic review method is applied in this study as prescribed by Tranfield et al. (2003) and consists of three stages. First, the literature review is scoped and planned. Second, the literature review is conducted by locating and selecting papers for review. Third, the findings from the literature review are reported and disseminated through a descriptive and thematic analysis of the selected papers.

The following two research databases were searched to locate literature:

- EBSCOhost research database
- SCOPUS research database

These databases were chosen because they include literature pertaining to SCM, logistics, and healthcare management. The keywords used to search the research databases can be found in Table 2.1. The keywords are variations of the words "logistics", "healthcare", "process", and different product flow types. The search was limited to peer-reviewed English language papers published between 1990 and 31 July 2016.

Table 2.1. Overview of keywords in literature search. Source: P1

Keywords I	Keywords II	Keywords III	Keywords IV	Excluding keywords
• Logistics • Supply chain management • Materials handling • Physical distribution	• Healthcare • Health care • Hospital	• Process • Value chain • Supply chain	• Pharmaceutical • Medicine • Drug • Medical supplies • Blood • Blood bank • Bed • Waste • Patient	• Humanitarian • Disaster • Clinical • Physician • Disease • Family planning • Home care • Pediatric • Public health research • Operations research • Operational research • Mathematical • Logistic regression analysis • Regression analysis • Malpractice

Applying a Boolean logic search string to the search databases using the keywords from Table 2.1 resulted in a list of 533 papers in the EBSCO database and 1,335 papers in the SCOPUS database. A list of selection criteria was established to identify the papers that support the purpose of the literature review. The selection criteria can be found in Table 2.2.

Table 2.2. Selection criteria for narrowing down number of papers

Selection criteria	**Rationale**
Inclusion criteria	
Contributions to knowledge about how to improve healthcare logistics processes are provided	This criterion is directly related to the review questions and the purpose of the literature review.
The physical distribution of materials within a hospital is in focus	This criterion reflects the scope of the review, which is limited to the physical distribution of materials within hospitals.
The hospital is included as one of the foci in the SC if not the main focus	The literature review focuses on the hospital and implications of interventions for the hospital.
Procurement is included if related to the process of replenishing hospital supplies	Papers focusing on the immediate and entire supply chain are included if they have implications for the hospital, in this case replenishment activities.
Exclusion criteria	
Focus on staff flows	Staff flows are not part of the focus of this paper, only materials flows, and are thus excluded from the review.
Focus on supplier collaboration and purchasing	As the literature study focuses on logistics processes within the hospital, how to improve supplier collaboration and purchasing is not the focus of this study.
Focus on outsourcing	The focus of this study is on the processes occurring within the hospital and how these processes could be improved by the hospital. Whether the hospital should shift responsibility to a third-party provider is not of relevance.
Focus on route optimization and optimal allocation of resources	Although route optimization and allocation of resources can improve performance, this study does not focus on mathematical methods for optimization, but rather changes that decision makers can choose to implement.
Focus on forecasting and scheduling	Although planning can improve the flow of goods, forecasting and scheduling will not be included in this study as it does not involve an intervention or improvement approach.
Focusing on home healthcare and telemedicine	Home healthcare and telemedicine is not part of this study as the focus is on the internal logistics processes in hospitals.

Based on the selection criteria, 81 papers were selected for the literature review. Out of the 81 papers, 39 papers were identified from the database searches and 42 papers were identified from cross referencing. These 42 derivative papers include some non-peer reviewed papers that contribute to knowledge about current practice for improving healthcare logistics processes. The process of narrowing down the list of papers to a manageable amount can be found in Figure 2.1.

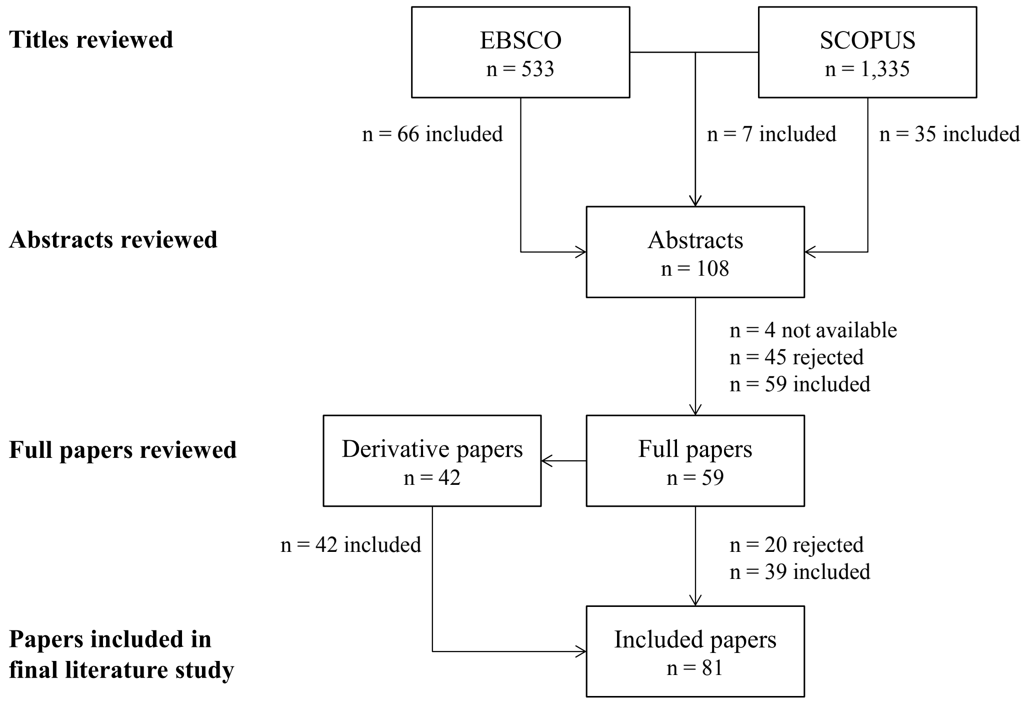

Figure 2.1. Paper selection process. Source: P1

A detailed description of the process for selecting articles to be included in the literature review can be found in P1.

2.3 DESCRIPTIVE ANALYSIS

The descriptive analysis analyzes the facts about the reviewed papers, including publications per year, journals and applied methods. The 81 papers included in this review were published between 1992 and 2016. The distribution of papers according to year of publication can be found in Figure 2.2. Figure 2.2 shows an increase of publications in the field since 1992 until a peak of ten publications in 2010 and a subsequent decline.

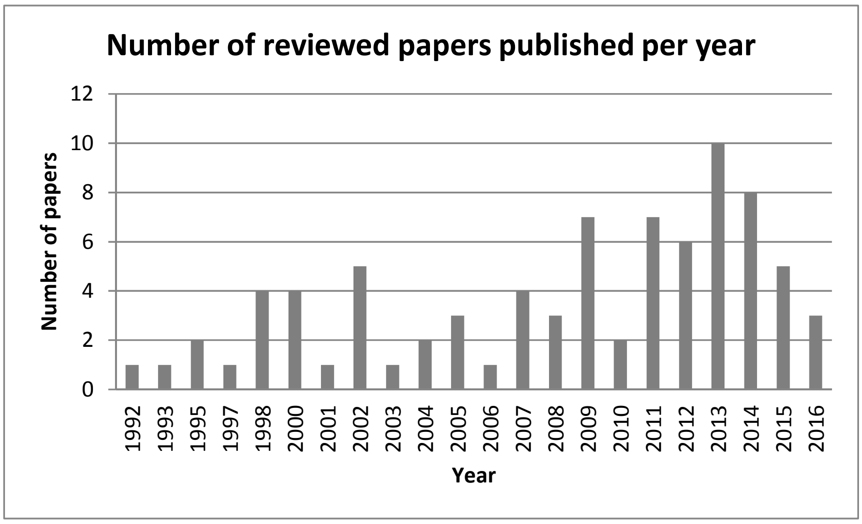

Figure 2.2. Papers included in review according to year of publication. Source: P1.

The distribution of papers across journals is found in Table 2.3. The papers are spread across 60 journals with the journal *Supply Chain Management: An International Journal* contributing with the most papers, i.e. six papers (7%).

Table 2.3. Distribution of journals

Journal	**No. of papers**	**Percentage**
Supply Chain Management: An International Journal	6	7 %
Transfusion	4	5 %
Production Planning & Control	3	4 %
Healthcare Financial Management	3	4 %
Decision Support Systems	2	2 %
Decision Sciences	2	2 %
International Journal of Production Economics	2	2 %
Business Process Management Journal	2	2 %
Supply Chain Forum: An International Journal	2	2 %
International journal of health care quality assurance	2	2 %
Health Care Management Science	2	2 %
International Journal of Physical Distribution & Logistics Management	2	2 %
International Journal of Operations & Production Management	2	2 %
Other journals	47	58 %

The dispersion of papers across journals and the relatively low number of publications over the years indicates an immature research field. This conclusion is further supported by the fact that case study research is the most prevalent method amongst the reviewed studies, see Table 2.4.

Table 2.4. Overview of applied methods. Source: P1.

Applied method	No. of papers	Percentage
Case study	42	52%
Survey	13	16%
Mathematical modelling	5	6%
Descriptive	5	6%
Simulation	4	5%
Literature review	4	5%
Mix of methods	3	4%
Editorial	2	2%
Discussion	1	1%
Diagnostic investigation	1	1%
Action Research	1	1%

2.4 THEMATIC ANALYSIS

The thematic analysis analyzes the content of the reviewed papers and is structured according to the review questions. First, challenges specific to healthcare logistics processes are identified (LRQ I). Second, the answers to LRQ II and LRQ III are briefly summarized. Third, LRQ IV will be answered by identifying benefits related to each identified intervention in LRQ II. Fourth, based on the thematic analysis answering LRQ I to IV, a decision framework is proposed to support decision makers in hospitals to make an informed decision about how to improve healthcare logistics processes.

2.4.1 LRQ I: CHALLENGES IN HEALTHCARE LOGISTICS

A number of challenges were identified in literature for healthcare logistics processes and are summarized in Table 2.5. Some of the challenges only relate to specific products, whereas most apply generally for healthcare logistics processes. Challenges mainly relate to quality, costs, inventory management, complexity, process efficiency, process immaturity, process and SC integration, and human resources and skills. In this case, process 'immaturity' refers to processes that are manual, paper based, lack standardization, are characterized by tacit knowledge, inconsistency, low utilization and lacking process data, traceability and visibility.

Table 2.5. Challenges in healthcare logistics identified in literature

Product type	**Challenge**	**Supporting literature**
Drugs, blood	Product availability from supplier	(Gebicki et al., 2014; Mustaffa and Potter, 2009)
	Perishability and product waste	(Beier, 1995; Beliën and Forcé, 2012; Fontaine et al., 2009; Gebicki et al., 2014; Gomez et al., 2015; Hemmelmayr et al., 2009; Mustaffa and Potter, 2009; Rautonen, 2007; Ritchie et al., 2000; Stanger et al., 2012)
	Special handling of items, e.g. temperature, product safety and security	(Beier, 1995; Chircu et al., 2014; Pan and Pokharel, 2007)
Drugs, blood, surgical tools	Potential stock-outs (patient safety issue)	(Beier, 1995; Beliën and Forcé, 2012; Fredendall et al., 2009; Stanger et al., 2012; de Vries, 2011)
Sterile supply	Interruptions in process that requires focus	(Fredendall et al., 2009)
General	Integrating with supplier systems	(Elleuch et al., 2014; Rautonen, 2007)
	Ensuring the right skills (sometimes clinical for sterilizing instruments)	(Callender and Grasman, 2010; Fredendall et al., 2009; Landry and Philippe, 2004; Stanger et al., 2012)
	Overstocking	(Aptel and Pourjalali, 2001; Beier, 1995; Kumar and Rahman, 2014; de Vries, 2011)
	Balancing quality and costs	(Fredendall et al., 2009; de Vries, 2011)
	Inventory shrinkage	(Bendavid et al., 2010; Böhme et al., 2016; Kumar and Rahman, 2014; Romero and Lefebvre, 2015; Yao et al., 2012)
	SC tiers operate independently / duplication of processes	(Callender and Grasman, 2010; Landry and Philippe, 2004; Nachtmann and Pohl, 2009)
	Fragmented processes and poor inter-functional integration	(Böhme et al., 2016; Landry and Philippe, 2004; Parnaby and Towill, 2009)
	Complexity of healthcare systems and healthcare SCs	(Beier, 1995; Böhme et al., 2013; Chircu et al., 2014; Fredendall et al., 2009; Nachtmann and Pohl, 2009; de Vries, 2011)
	Unpredictability and uncertainty (demand, supply, capacity)	(Anand and Wamba, 2013; Bailey et al., 2013; Beier, 1995; Böhme et al., 2013; Fontaine et al., 2009; Gebicki et al., 2014; Jarrett, 1998; Yau et al., 1998)
	Low capacity at bottleneck/lack of personnel	(Elleuch et al., 2014; Fredendall et al., 2009)
	Delays in delivery of (critical) items	(Beier, 1995; Parnaby and Towill, 2009; Thomas et al., 2000)
	Process immaturity	(Anand and Wamba, 2013; Bailey et al., 2013; Böhme et al., 2013, 2016; Fredendall et al., 2009; Kumar and Rahman, 2014; Landry and Philippe, 2004; Nachtmann and Pohl, 2009)
	Inefficient processes	(Anand and Wamba, 2013; Böhme et al., 2016; Nachtmann and Pohl, 2009; Yao et al., 2012; Yau et al., 1998)
	Political agendas, lack of executive commitment, misalignment of incentives within hospitals and across SC	(Böhme et al., 2013, 2016; Callender and Grasman, 2010; McKone-Sweet et al., 2005; de Vries, 2011)
	Wrong people performing tasks	(Bloss, 2011; Landry and Philippe, 2004)
	High SC costs	(Böhme et al., 2016; Romero and Lefebvre, 2015)

2.4.2 LRQ II AND LRQ III: INTERVENTIONS AND CONTINGENT FACTORS

The identified types of interventions relate to either 1) business process management (BPM), 2) logistics and SCM interventions, 3) technological interventions, or 4) organizational interventions. Each of these four themes consists of sub-themes that specify the types of interventions identified in literature. Contingent factors were identified for technological interventions and “replenishment systems”, which is a sub-theme of logistics and SCM interventions. BPR is the only other theme for which contingent factors could be identified. According to Kumar and colleagues, BPR is suitable for a healthcare environment because of repetitive tasks, high volumes and tangible items (Kumar et al., 2008). The identified contingent factors indicate under which circumstances a particular type of intervention is recommendable.

Interventions. The themes and underlying sub-themes identified in literature are summarized in Table 2.6. P1 elaborates on the literature identified for each sub-theme.

Table 2.6. Overview of sub-themes identified in literature

BPM	Logistics and SCM	Technology	Organization
Process characteristics • Non-specific items • Pharmaceuticals • Blood products • Sterile supplies *BPM approaches* • BPR • Cellular operations • Performance measurement • Benchmarking • Process standardization	*Replenishment systems* • Replenishment policy • JIT • Stockless system • Vendor managed inventory (VMI) • Single dose system *SC design* • SC integration • SC and logistics innovation • Responsive SCs	• Automated transport • Automated storage and retrieval • Barcodes • RFID • Information and communication technologies (ICTs)	• Organizing logistics activities • Human resource management (HRM) • Centralization vs. decentralization • Organizational and social setting

The literature review revealed that the organizational aspect of healthcare logistics is the least investigated theme and that the sub-themes of BPM are scarcely investigated as well.

Contingent factors. Contingent factors were identified in the reviewed literature for replenishment systems, i.e. a sub-theme of logistics and SCM, and for technological interventions, except for ICTs. Table 2.7 provides an overview of the contingent factors for SCM and logistics interventions and Table 2.8 provides an overview of contingent factors identified for technological interventions.

Contingent factors were only identified for replenishment systems, i.e. replenishment policy (RP), JIT, stockless systems (SLS), VMI, and single dose systems (SD), and for technologies, i.e. automated transport (AT), automated storage and retrieval (ASR), barcodes (BC) and RFID, but not for ICTs. No contingent factors were identified for organizational interventions and BPM apart for BPR. Literature indicates that BPR is applicable to healthcare logistics processes because of repetitive tasks, high volumes and tangibility (Kumar et al., 2008).

Table 2.7. Contingent factors identified for SCM and logistics interventions

Contingent factors	**Relation of factors to interventions**	**SCM/logistics interventions**				
		RP	***JIT***	***SLS***	***VMI***	***SD***
Demand variability	Replenishment model should consider demand variability (Wang et al., 2015). Demand variability affects safety stock (Aptel and Pourjalali, 2001; Beier, 1995). Apply EOQ to reduce stock levels (Beier, 1995). Combine stockless with virtual pharmacy to cope with unexpected demand (Danas et al., 2002).	X		X		
Supply variability	Develop contingency plan in conjunction with JIT to avoid SC disruptions (Jarrett, 1998).		X			
Product criticality	Consider product criticality when developing a RP (Gebicki et al., 2014; Perera et al., 2009)	X				
Consequences of stock-outs	Consider consequences of stock-outs when developing a replenishment policy (Gebicki et al., 2014; Perera et al., 2009)	X				
Shelf-life / perishability	RP depends on shelf-life (Pan and Pokharel, 2007)	X				
Service level	Inventories are a balance of ordering costs, carrying costs and service levels and safety stocks may be necessary for high service levels (Gebicki et al., 2014). Consider the effect on quality of service (Pinna et al., 2015).	X				
Safety	Consider safety effects of any system (Pinna et al., 2015).	X	X	X	X	X
Total cost of a system	Consider total costs of a system rather than short term gains (Marino, 1998). Consider costs vs. financial benefits (Pinna et al., 2015). Inventories are a balance of ordering costs, carrying costs and service levels (Gebicki et al., 2014).	X	X	X	X	X
Monetary value	JIT not recommended for low value items (Jarrett, 1998). JIT is inefficient for special products, i.e. rarely used and often expensive (Persona et al., 2008).		X			

Table 2.7 (continued). Contingent factors identified for SCM and logistics interventions

Contingent factors	**Relation of factors to intervention**	**SCM/logistics interventions**				
		RP	***JIT***	***SLS***	***VMI***	***SD***
Product volume	RP depends on the quantity (Pan and Pokharel, 2007). JIT recommended for high volume items (Jarrett, 1998; Whitson, 1997). Stockless systems usually used for small product categories (Kim and Schniederjans, 1993).	X	X	X		
Frequency of product use	Stockless is usually used for small product categories and frequently used items (Kim and Schniederjans, 1993). JIT is inefficient for special products, i.e. rarely used and often expensive (Persona et al., 2008).		X	X		
Repetition	Repetitive tasks makes materials handling in healthcare suitable for JIT (Whitson, 1997).		X			
Tangibility	Tangibility makes materials handling in healthcare suitable for JIT (Whitson, 1997).		X			
Product bulkiness	RP depends on product bulkiness (Pan and Pokharel, 2007).	X				
Inventory level and mix	Inventory level and mix concerns the RP, and cost effects should be considered for any system (Marino, 1998).	X	X	X	X	X
Ordering patterns	Ordering patterns concerns the RP, and cost effects should be considered for any system (Marino, 1998).	X	X	X	X	X
Supplier proximity and accessibility	JIT and stockless systems unsuitable for long distances and isolation (Van de Klundert et al., 2008; Kumar et al., 2008; Mustaffa and Potter, 2009; Pan and Pokharel, 2007; Wilson et al., 1992). VMI solutions suitable where suppliers are close by (Pan and Pokharel, 2007). Others argue it is suitable for remote areas (Mustaffa and Potter, 2009). Distance and the cost effect should be considered for any system (Marino, 1998).		X	X	X	X
Use of e-commerce/ IT capabilities	The use of e-commerce makes the implementation of JIT and VMI easier (Marino, 1998; Pan and Pokharel, 2007). RFID is most beneficial in combination with continuous replenishment (Çakici et al., 2011).	X	X		X	
Distributor's ability to support planning/ forecasting	The cost effect of the distributor's ability to support in planning and forecasting should be considered for any system (Marino, 1998).		X	X	X	X
Willingness to change	The cost effect of the willingness to change should be considered for any system (Marino, 1998).		X	X	X	X

Table 2.8. Contingent factors identified for technological interventions

Contingent factors	**Relation of factors to intervention**	**Technological interventions**			
		AT	***ASR***	***BC***	***RFID***
Load capacity	Load capacity influences what type of technology is suitable for transporting specific items (Landry and Philippe, 2004).	X			
Time-criticality	The delivery of certain product types is time-critical and may require speedy delivery at all times of the day (Bailey et al., 2013). Average waiting time may influence choice of technology – pneumatic tube system found to perform better than AGV solution for transporting blood samples (Jørgensen et al., 2013).	X	X		
Level of process automation	Automatic counting and reordering achieved through RFID compared to barcodes (Çakici et al., 2011).			X	X
Frequency of use	The number of times barcodes are used affects the financial viability of the solution (Maviglia et al., 2007).			X	
Efficiency of technology	Simultaneous and multiple reads possible with RFID, but not barcodes (Çakici et al., 2011).			X	X
Data capacity	Higher data capacity for RFIDs than barcodes (Çakici et al., 2011).			X	X
Line of sight requirement	Depending on the process, line of sight to scan an object may or may not be required. RFIDs require no line of sight, barcodes do (Anand and Wamba, 2013; Kumar and Rahman, 2014).			X	X
Data encryption	The level of data encryption is better for RFIDs than barcodes (Çakici et al., 2011; Coustasse et al., 2013).			X	X
Read range capabilities	RFIDs can be read at longer distances than barcodes (Anand and Wamba, 2013).			X	X
Need for real-time tracking	RFIDs enable real-time tracking of items, barcodes do not (Anand and Wamba, 2013; Çakici et al., 2011).			X	X
Durability	Barcodes and RFID tags are exposed to the environment and may wear and tear. RFIDs are more durable than barcodes (Anand and Wamba, 2013; Çakici et al., 2011).			X	X
Stock-taking costs vs. data accuracy	The ratio between stock-taking costs and inventory accuracy determines whether a barcoding or RFID-system outperforms the other (Chan et al., 2012).			X	X
The network effect	The decision to use RFID or barcodes may depend on what everyone else uses (Çakici et al., 2011; Romero and Lefebvre, 2015).			X	X

2.4.3 LRQ IV: Benefits of interventions

A number of benefits were identified for the interventions found in literature. Table 2.9 summarizes the benefits identified in the reviewed literature for each type of intervention, i.e. sub-theme. An overview of the supporting literature for each identified benefit can be found in Appendix A.

The identified benefits each relate to one of the following categories:

- Process performance and cost savings
- Quality
- Inventory management
- Flow management
- Patient care
- Compliance
- Staff
- Procurement
- Information management and supply chain coordination

Thus, the above listed aspects of healthcare logistics can be improved through the various interventions identified in literature.

The benefits identified for each intervention can be viewed as an incentive for implementing a particular intervention and for selecting between interventions. However, some authors specified certain benefits as decision criteria for selecting between technologies. These decision criteria are denoted with a "*" in Table 2.9 and are listed separately in Table 2.10.

Table 2.9. Benefits identified for each intervention

Identified benefits	BPM					SCM and logistics								Technology					Organization			
	BPR	Cellular ops.	Perf. measurement	Benchmarking	Process std.	RP	JIT	SLS	VMI	SD	SC integration	SC/logist. innov.	Responsive SC	AT	ASR	BC	RFID	ICTs	Org. logist. activ.	HRM	(De)centralization	Social/org. setting
Process performance and cost savings																						
1.1 Increased efficiency*	X	X	X		X		X		X		X	X				X	X	X			X	X
1.2 Improved effectiveness			X		X																	
1.3 Increased productivity																	X	X				
1.4 Shorter processing time																	X	X				
1.5 Shorter cycle time*																X	X	X				
1.6 Lead time*											X			X								
1.7 Cost savings*	X	X		X		X	X	X	X		X	X			X	X	X	X			X	
1.8 Improved SC performance			X	X		X					X	X								X	X	X
1.9 Improved flexibility/responsiveness									X		X		X									
1.10 Increased device utilization																	X	X				
Quality																						
2.1 Error reductions							X		X							X	X	X				
2.2 Improved service levels					X		X	X	X		X	X					X	X			X	
2.3 Increased reliability and routinization				X								X					X	X			X	
2.4 Reductions in counterfeit drugs																	X					
2.5 Improved data accuracy*									X						X	X	X	X				
Inventory management																						
3.1 Improved product availability						X			X						X		X					
3.2 Stock level reductions						X	X	X	X	X					X		X	X				
3.3 Improved inventory visibility*									X						X	X	X					
3.4 Fast ID of end-of-life/obsolete stock																		X				
3.5 Reductions in theft and wasted products*									X							X	X	X				
3.6 Reduced rate of emergency orders															X							
3.7 Improved demand and supply variability management						X	X	X										X				

Table 2.9 (continued). Benefits identified for each intervention

Identified benefits	BPM					SCM and logistics								Technology					Organization			
	BPR	**Cellular ops.**	**Perf. measurement**	**Benchmarking**	**Process std.**	**RP**	**JIT**	**SLS**	**VMI**	**SD**	**SC integration**	**SC/logist. innov.**	**Responsive SC**	**AT**	**ASR**	**BC**	**RFID**	**ICTs**	**Org. logist. activ.**	**HRM**	**(De)centralization**	**Social/org. setting**
Flow management																						
4.1 Improved operational flows*	X	X			X		X				X						X	X				
4.2 Improved reverse logistics*			X													X	X	X				X
4.3 Improved visibility of flows																	X					
4.4 Reductions in waiting time														X			X					
4.5 Improved planning and control*			X									X					X	X				
4.6 Improved administrative processes		X									X				X		X	X				
Patient care																						
5.1 Reductions in delays for patients																	X					
5.2 Increased patient care quality and safety*									X							X	X	X				X
Compliance																						
6.1 Enhanced documentation																	X					
6.2 Temperature assurance																	X					
6.3 Improved maintenance																	X	X				
Staff																						
7.1 Improved work conditions and staff satisfaction															X		X					
7.2 Elimination of manual processes									X		X			X	X		X	X				
7.3 Time savings						X	X	X	X	X	X			X	X		X	X	X		X	

Table 2.9 (continued). Benefits identified for each intervention

Identified benefits	BPM					SCM and logistics								Technology					Organization			
	BPR	**Cellular ops.**	**Perf. measurement**	**Benchmarking**	**Process std.**	**RP**	**JIT**	**SLS**	**VMI**	**SD**	**SC integration**	**SC/logist. innov.**	**Responsive SC**	**AT**	**ASR**	**BC**	**RFID**	**ICTs**	**Org. logist. activ.**	**HRM**	**(De)centralization**	**Social/org. setting**
Procurement																						
8.1 Improved readiness of purchase orders*																X	X					
8.2 Reduced order fre-quency and volume							X															
8.3 Reduced consumption and overbuy-ing							X										X					
8.4 Reduc-tions in back orders																	X					
8.5 Improved supplier integration and relation-ships							X	X	X		X	X					X	X			X	
Information management and supply chain coordination																						
9.1 Improved information storage*									X		X						X	X				
9.2 Real-time data access																	X	X				
9.3 Improved SC info sharing and processing																	X	X				
9.4 Improved SC commu-nication *																		X				
9.5 Improved CPFR*																		X				

Table 2.10. List of decision criteria identified in literature for selecting technologies

Decision criteria for selecting technologies	
• Increased efficiency	• Improved reverse logistics
• Shorter cycle time	• Improved planning and control
• Shorter lead time	• Increased patient care quality and safety
• Lower costs	• Improved readiness of purchase orders
• Improved data accuracy	• Improved information storage
• Improved inventory visibility	• Improved SC communication
• Reductions in theft and wasted products	• Improved collaborative planning, forecasting and replenishment (CPFR)
• Improved operational flows	

2.4.4 Mapping healthcare logistics literature

The literature review shows that healthcare logistics literature can be divided into the themes BPM, logistics and SCM, technology, and organization. In addition, each of the identified themes can be divided into a number of sub-themes. The themes and sub-themes of healthcare logistics literature are illustrated in Figure 2.3. There are 53 papers related to logistics and SCM interventions, 48 papers consider technological interventions, 42 papers relate to BPM and 28 papers to organizational interventions.

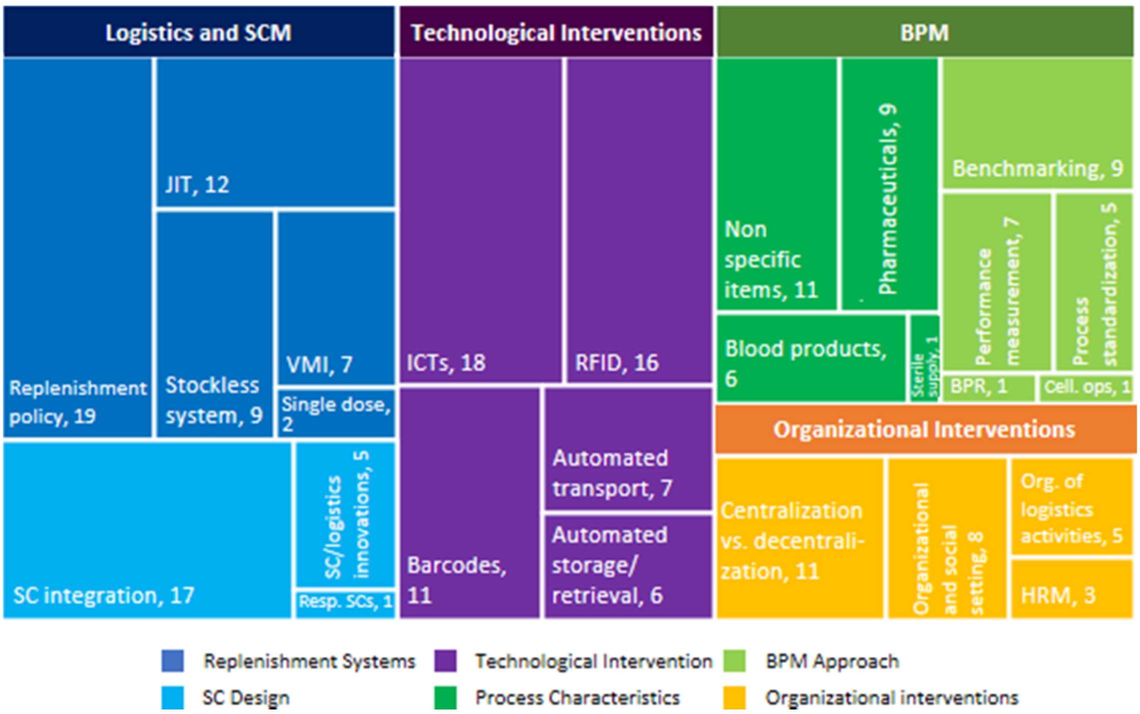

Figure 2.3. Illustration of healthcare logistics literature themes

Each of the major themes in literature, i.e. BPM, SCM and logistics, technology, and organization, do not function separately, but are interrelated, and can support each other in improving healthcare logistics or in some cases affect each other negatively (P1). Papers will therefore often cover more than one theme. Figure 2.4 illustrates how many themes each of the reviewed papers covers and subsequently how many of the papers cover each theme. The components of the figure indicate theme coverage and number of papers covering different combinations of themes. The components that contain numbers denoted with a "*" and "[]" relate to the same bundle of papers, respectively. Thus, three papers contribute to the BPM and organizational aspects simultaneously and 14 papers contribute to the logistics/SCM and technological aspects simultaneously. Figure 2.4 shows that the organizational aspect of healthcare logistics is investigated the least and is in need of further research. BPM is the second least researched topic and a review of the BPM literature shows that each of the sub-themes of BPM in healthcare logistics leaves much to be discovered in future research.

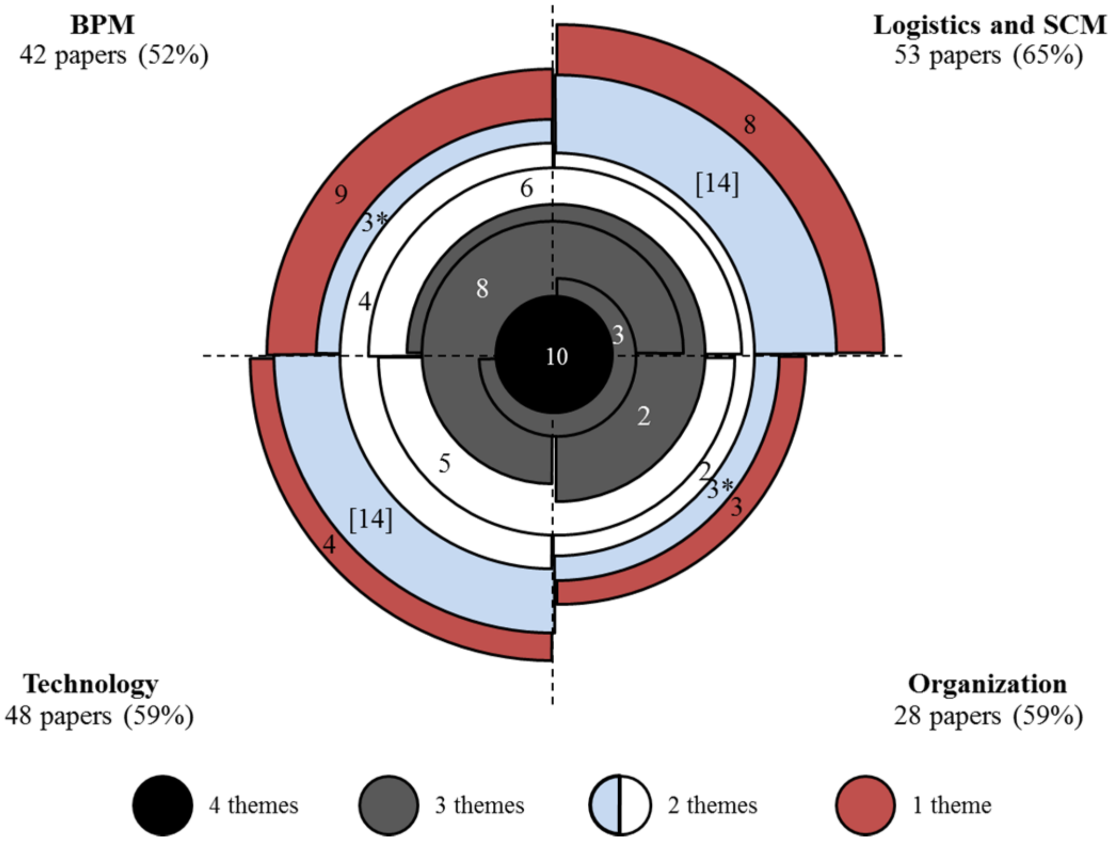

Figure 2.4. Illustration of reviewed literature

2.5 Framework for improving healthcare logistics (Part I)

This literature review identified the benefits of applying different interventions in healthcare logistics. Recognizing a challenge for a healthcare logistics process may lead to the implementation of an intervention, which in turn produces a benefit that alleviates the identified challenge. The relation between the challenge, intervention, and benefits produced by interventions is illustrated in Figure 2.5.

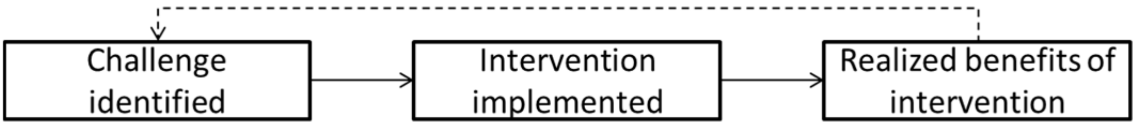

Figure 2.5. Relation between challenge, intervention and benefits of intervention

Each identified intervention relates to BPM, SCM and logistics, technologies, or organization. Table 2.9 shows the link between interventions and their possible benefits identified in the reviewed literature. Each of these benefits could alleviate challenges identified for healthcare logistics processes.

Table 2.11 matches challenges with the identified benefits that could alleviate these challenges. Thus, a combination of Table 2.9 and Table 2.11 provides the following links: 1) identification of benefits that can address particular challenges, and 2) identifying interventions that can provide the desired benefits to address the challenges experienced in healthcare logistics. However, benefits and challenges do not match up perfectly. I.e. not all challenges are addressed by benefits and not all benefits address a challenge. Three challenges were not directly addressed by benefits identified in literature:

1) Ensuring the right skills
2) Integrating with supplier systems
3) Political agendas, lack of executive commitment and misalignment of incentives within hospitals and across the SC

Although benefits alleviating these challenges were not specifically identified in the reviewed literature, some of the sub-themes do address a part of these challenges. First, HRM is concerned with staff development. Furthermore, ensuring the right skills is an inherent part of BPR (Hammer and Champy, 1993). Second, the point of difficulties in integrating with supplier systems is an issue that must be dealt with when integrating with suppliers and setting up replenishment systems such as JIT and VMI. Such issues must be handled in collaboration with the IT department of both the supplier and the hospital. Third, political agendas, lack of executive commitment and misalignment of incentives are management issues that must be dealt with within and across organizations. Thus, alignment of incentives can be achieved through incentive schemes and performance management. Executive commitment is both a strategic matter and a matter of persuasion from logistics managers. Political agendas are difficult to manage but can in part be addressed by aligning incentives.

Table 2.11. Matching challenges and identified benefits

Challenges in healthcare logistics	**Numbered benefits addressing challenges** (benefits numbered according to Table 2.9)
Conditions of system and processes	
Complexity of healthcare systems and healthcare SCs	1.9; 2.1; 2.3; 3.7; 4.3; 4.5; 9.3; 9.4; 9.5
Inefficient processes	1.1; 1.3; 1.4; 1.5; 1.6; 1.10; 2.1; 4.1; 4.2; 4.4; 4.6; 7.2; 7.3
High SC costs	1.1; 1.3; 1.7; 1.10; 2.1; 3.2; 3.5; 3.6; 7.2; 7.3; 8.3
Process immaturity	2.3; 2.5; 3.3; 3.6; 3.7; 4.1; 4.2; 4.3; 4.5; 6.1; 7.2; 9.1; 9.2; 9.3
Balancing quality and costs	1.1; 1.2; 1.6; 1.7; 2.1; 2.2; 5.1; 5.2
Delays in delivery of (critical) items	1.4; 1.5; 1.6; 1.9; 2.2; 3.1; 4.1; 4.4; 4.5; 5.1; 5.2; 7.3; 8.1
Unpredictability and uncertainty (demand, supply, capacity)	2.1; 2.3; 2.5; 3.3; 3.6; 3.7; 4.3; 4.5; 8.5; 9.2; 9.3; 9.4; 9.5
Inventory management	
Product availability from supplier	1.9; 2.3; 3.1; 3.6; 3.7; 4.3; 4.5; 8.1; 8.4; 9.3; 9.5
Perishability and product waste	1.5; 1.6; 1.9; 3.5; 6.2
Special handling of items	2.1; 2.4; 6.2
Overstocking	3.2; 8.2; 8.3
Potential stock-outs (patient safety issue)	1.9; 2.2; 2.3; 3.1; 3.3; 3.4; 3.5; 3.7; 4.1; 4.2; 4.3; 4.5; 9.5
Inventory shrinkage	3.5; 6.2
SC integration	
SC tiers operate independently / duplication of processes	1.8; 8.5; 9.2; 9.3; 9.4
Fragmented processes and poor inter-functional integration	4.1; 4.2; 4.3; 4.5; 9.3; 9.4
Integrating with supplier systems	N/A
Resources	
Wrong people performing tasks	7.1; 7.2; 7.3
Interruptions in process that requires focus	4.1
Low capacity at bottleneck/lack of personnel	1.1; 1.3; 1.4; 1.5; 2.1; 4.1; 4.5; 7.3
Ensuring the right skills (sometimes clinical for sterilizing instruments)	N/A
Political agendas, lack of executive commitment, misalignment of incentives within hospitals and across SC	N/A

One of the benefits achieved through the identified interventions does not address a particular challenge experienced for healthcare logistics processes. *Improved maintenance* was identified as a possible benefit from implementing RFID and ICTs but does not address a particular challenge. However, one could argue that improved maintenance improves utilization of devices and equipment and furthermore reduces costs due to a longer product life-span.

Based on the findings from the literature review, a framework for improving healthcare logistics processes is proposed. The framework serves as a decision tool for managers in improving healthcare logistics processes. The framework is illustrated in Figure 2.6 and can either be used to address specific challenges or merely to achieve certain benefits. The proposed framework consists of three overall steps. First, identify the challenges experienced in a specific healthcare logistics process and match with benefits to remedy these challenges. Another option is to focus on the benefits, i.e. improvements, desired for the process. Second, use Table 2.11 to match challenges, benefits and interventions to narrow down the number of interventions to those that provide the desired benefits. Third, select between the remaining possible interventions, taking contingent factors into consideration. The contingent factors are found in Table 2.7 for SCM and logistics interventions and Table 2.8 for technological interventions. It is not the intent of the framework to propose that all possible interventions should be implemented, but the framework provides support for SCM practitioners in deciding which interventions to implement. Additional analyses may be necessary, e.g. an economic analysis and ensuring alignment with the hospital's overall strategy. Furthermore, as the literature review revealed, it is important to consider the interrelations between processes, SCM and logistics, technologies, and the organization.

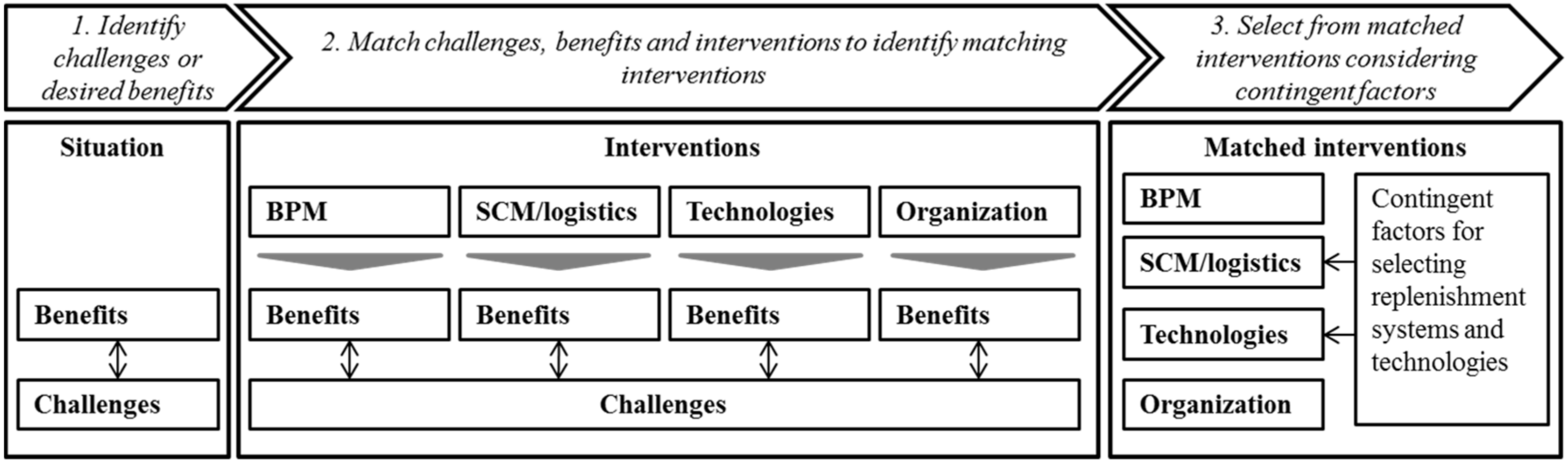

Figure 2.6. Framework (Part I) for improving healthcare logistics processes

In the following, a simple example of how to use the framework in Figure 2.6 is provided. Imagine a logistics manager in a hospital struggling with inventory shrinkage, i.e. loss of inventory due to theft, loss or damage. According to Table 2.9, benefits *3.5 Reductions in theft and wasted products* and *6.2 Temperature assurance* can help alleviate inventory shrinkage. In this case, inventory shrinkage concerns medical devices and is not dependent on temperature, which means that temperature assurance is not an issue. This leaves *3.5 Reductions in theft and wasted products* with the options of VMI, barcodes, RFID and ICTs. Table 2.7 and 2.8 then provide an overview of specific considerations for selecting the suggested interventions. E.g. for barcodes and RFIDs, the level of automation may be of particular interest, i.e. automatic count of stock. Considering the list of contingent factors identified in Table 2.7 and Table 2.8 can therefore help narrow down the list of possible interventions to a manageable number of options which can be subject to further analysis or in itself provide a final decision.

2.6 Limitations of review and framework

This literature review is not without limitations. The study aims to enfold literature which contributes to the understanding of how to improve healthcare logistics processes. The scope of the literature review is limited by the keywords applied to the research databases and the specified inclusion and exclusion criteria for selecting articles. Studies advocating mathematical methods as a tool for improvement are not included in this review but are treated in the literature review by Dobrzykowski and colleagues regarding healthcare management (Dobrzykowski et al., 2014) and Volland et al. for materials logistics in hospitals (Volland et al., 2016). Furthermore, the literature review reflects current state-of-the-art within the field of healthcare logistics, which will inevitably change over time, especially considering the rapid developments in technologies, including disruptive technologies. In addition, the benefits identified for particular interventions is limited to findings from the healthcare logistics literature, whereas application and research in other industries are likely to be more developed and could provide valuable insights for the application and research within healthcare logistics.

The limitations of the literature review have implications for the limitations of the framework developed based on the literature review. Based on the limitations of the review, it follows that the developed framework reflects the current application and identified benefits of interventions in healthcare logistics. For the framework to reflect state-of-the-art, the interventions, benefits and contingent factors must be updated regularly to reflect current and potential practice based on findings from other industries and research fields.

2.7 Theoretical foundation and filling the gap in literature

This PhD thesis delineates the frontier of extant literature and subsequently of what is known about the field of healthcare logistics. Furthermore, the thesis contributions expand the frontier of current knowledge in the research field. In addition to contributing with an account of the current state of healthcare logistics literature, a framework is developed in this thesis for improving healthcare logistics processes. The first part of the developed framework is based on the literature review and has been introduced in Figure 2.6. The second part of the framework is based on empirical studies of healthcare logistics processes, i.e. case studies conducted at Danish and US hospitals. The theoretically based framework is therefore extended with an empirically founded component developed in the Results. The framework can be used as a decision support tool for improving logistics processes in healthcare.

This research project contributes to all of the four themes identified in literature, corresponding to the following four theoretical streams of literature:

- BPM
- Logistics and SCM
- Technology assessment and justification
- Human factors and organizational management

This thesis contributes to BPM literature with 1) a method for benchmarking, 2) suggestions for performance metrics and 3) a framework for assessing the design of a process. For *logistics and SCM literature,* a method for assessing SC design is provided. The thesis contributes to *technology assessment literature* by providing a method for assessing and justifying the implementation of technologies in a healthcare logistics process. Finally, contributions to *organizational literature* include metrics for measuring performance of logistical staff in hospitals and emphasis on the importance of employee retention and absenteeism for the quality of healthcare logistics processes. Contributions of this thesis and suggestions for future research will be detailed in the Conclusion.

It follows from the literature review and the described scientific contributions of this study that the field of research investigated in this thesis centers around the interfaces of four theoretical streams of literature, which is illustrated in Figure 2.7. The theoretical foundation of this thesis is a combination of the four streams of literature for a healthcare logistics setting.

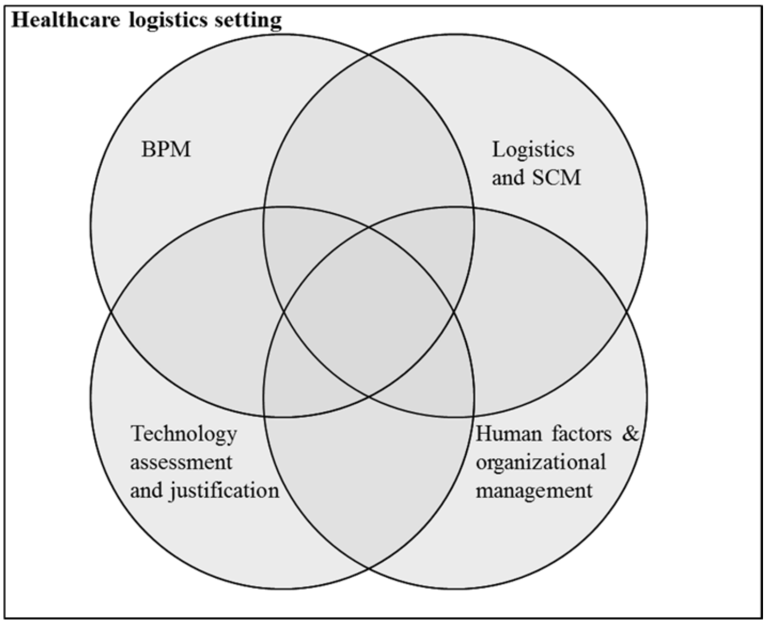

Figure 2.7. Theoretical foundation of thesis – at the interface of literature streams

The empirical study in this thesis focuses on each of the four literature streams by examining the following four constructs, i.e. relabeled literature streams/types of interventions, and their interrelations:

- Procedure
- Logistics
- Technology
- Structure

These four constructs provide the pillars of the empirically founded research and the framework developed in this thesis.

2.8 CHAPTER SUMMARY

This chapter reports on the thesis' systematic literature review and is largely based on P1. In this paper, the different types of interventions for improving healthcare logistics processes were identified together with the contingent factors for implementing technologies and replenishment systems. Moreover, four themes emerged from an analysis of the literature: 1) BPM, 2) logistics and SCM interventions, 3) technological interventions and 4) organizational interventions. In addition to the findings from P1, the literature review in this thesis provides an overview of the challenges specific to healthcare logistics processes and the benefits identified for each type of intervention. A framework was developed based on the reviewed literature to help decision makers in hospitals improve their processes. Limitations of the literature review are described and the theoretical foundation and contributions to scientific research are provided in brief. The theoretical foundation of this thesis is based on four literature streams: 1) BPM, 2) logistics and SCM, 3) technology assessment and justification, and 4) human factors and organizational management.

3 METHODOLOGY

The methodology of this study is presented in this chapter. The chapter is structured as follows. First, the philosophical position of this study is clarified. The three research questions presented in the Introduction are then broken down into sub-questions, followed by an outline of the research objectives and investigated constructs. Theory building within SCM and OM is then discussed in relation to this thesis. A justification and description of the case study as research design and mixed methods as research strategy follows. Moreover, the approach for data collection and analysis are presented, followed by an account of how quality of research is ensured. Finally, the nature of scientific contributions and practical implications are explained.

3.1 PHILOSOPHICAL POSITION OF THESIS

The philosophical stance adopted in this study is critical realism, which originated with British philosopher Roy Bhaskar in the 1975 book *A Realist Theory of Science*. In the following will be referred to the 2008 edition of the book (Bhaskar, 2008). Critical realism represents a realist ontology and a relativist epistemology. Ontology refers to the theory of being, i.e. what is real, and epistemology refers to the theory of knowledge, i.e. what is knowledge and what can be known and understood. In critical realism, reality exists independently from human thought, i.e. reality exists regardless of what is known (Bhaskar, 2008; Wynn Jr. and Williams, 2012).

Critical realism has a stratified ontology consisting of three domains of reality: the *empirical domain*, the *actual domain* and the *real domain* (Bhaskar, 2008). Within critical realism, causal relationships are located between a generative mechanism and observed regularity. The real domain contains generative mechanisms and exists independently of the observer. The actual domain consists of events caused by generative mechanisms in the real domain and, again, exists independently of the observer. The empirical domain consists of events that the observer experiences. The events occurring in the actual domain may or may not be observed by observers and may in addition be understood in different ways by observers (Bhaskar, 2008). Causal relationships are not necessarily observable, thus it may only be the effect of a generative mechanism that is observed. However, the unobserved generative mechanism may still be included to explain theory. From a critical realist point of view, the causal relationship is context specific. The context affects the generative mechanism and is an important part of understanding how the generative mechanism works (Easton, 2010). Different contexts are therefore explored for the investigated cases in this study.

Critical realism exerts a transcendental realist view and assumes that the world is socially construed (Easton, 2010). Critical realists seek explanations rather than prediction because social systems cannot be contained and causes cannot be isolated as for laboratory experiments (Bhaskar, 2008; Wynn Jr. and Williams, 2012). It is possible to know what reality is, albeit unlikely to understand the whole truth (Easton, 2010). Thus, there is a reality, but knowledge is relative and theory-dependent (Bhaskar, 2008; Aastrup and Halldórsson, 2008).

Based on a critical realist point of view, Aastrup and Haldórsson (2008) provide justification for the use of case studies in logistics research. First, case studies reach the causal depth to reveal the real domain of logistics. Second, case studies can uncover generative mechanisms. Third, case studies include causal powers and effects of intentions of agents, e.g. individuals, firms or organizational units. Furthermore, the authors argue that the justification of case studies should not only lie in the capacity of a complementary or exploratory role but of a primary role in generating knowledge.

The realist view is compatible with case study research (Yin, 2014; Aastrup and Halldórsson, 2008). Easton argues that critical realism not only provides the justification for the use of case studies, but also guidelines for how to conduct case research (Easton, 2010). First, a case study is a well suited research method within critical realism to investigate clearly bounded and complex phenomena. In this study, the complex phenomenon investigated is the improvement of healthcare logistics processes. Second, the entities/objects characterizing the investigated phenomenon should be identified. The processes investigated for this study are characterized and factors impacting the improvement decision identified. Third, data should be collected to establish plausible causal mechanisms. This study investigates two types of generative mechanisms and events. One type is the identified impact factors as generative mechanism with the decision to implement changes to improve healthcare logistics processes as the event. Another type is the possible interventions as generative mechanism and the consequence of improved healthcare logistics processes as event. Fourth, explanations are interpretivist in character and researchers' understanding of a subject's understanding must be included. These understandings are described in the case study descriptions and in the data analysis. Fifth, retroduction, also referred to as abductive reasoning, is the key epistemological process recognized by critical realists. For the iterative process of abduction, data is coded and re-coded and sites are revisited. Finally, the quality of an explanation should be assessed, i.e. determining whether an explanation is "good" or "acceptable". A "judgmental rationality" is applied, which evaluates existing arguments to reach a reasonable judgement of the reality.

Critical realist research is considered an iterative process and something that is improved over time (Dubois and Gadde, 2002). Similarly, abduction is an iterative process. Abduction is rooted in extant theory, which is then compared to observations (Voss et al., 2016). This iterative process was evident in the coding and recoding of data, repeated site visits, and the several iterations of the framework. The iterative approach corresponds well with theory building and the iterative process of case studies (Easton, 2010; Eisenhardt, 1989; Ellram, 1996; Verschuren, 2003). Furthermore, the same study was conducted in several iterations, i.e. the same study was repeated for different contexts.

An inductive approach is typically used for theory building (Voss et al., 2016), whereas an abductive research approach is apt for theory testing and refinement, i.e. for mature theories (Voss et al., 2016; Åhlström, 2016). Healthcare logistics is a relatively new research field. In this case, abductive research is used for refining a framework developed by Jørgensen (Jørgensen, 2013). However, this study has some similarities to an inductive study and therefore partly refines a framework and builds theory within healthcare logistics.

Case studies provide an in-depth understanding of a case and the case context as well as the underlying mechanisms that generate a certain outcome. The observed outcomes may be observed as regularities within and across cases (Bryman, 2012). Identifying the generative mechanisms makes it possible to change the status quo, which is the aim and objective of this research.

The use of mixed methods in this study is in accordance with critical realism as the use of multiple methods and data sources enables a deeper understanding of causality (Wynn Jr. and Williams, 2012). Furthermore, critical realism is compatible with the field of SCM and OM due to the focus on empirical data and causality within critical realism and the focus on understanding causalities of complex system within SCM and OM (Rotaru et al., 2014).

3.2 Research aim and research questions

The research questions are closely related to the aim of the research and the problem statement. The problem statement was specified in the Introduction and the research aim of this study was formulated as follows:

Research aim: *Provide theoretically and empirically based evidence for improving healthcare logistics processes to both expand the knowledge base of healthcare logistics and provide a decision tool for managers to improve healthcare logistics processes.*

The feasibility of a research question, and consequently the research method, depends on the maturity of the research field. I.e. exploratory and descriptive research is suitable for a nascent research field whereas explanatory and prescriptive research is suitable for a more mature research field (Åhlström, 2016). As the literature review revealed, the field of healthcare logistics research is relatively new, but some literature does exist in the field. The research field is therefore developing and is neither nascent nor mature. The literature base of the research field is prescriptive to a limited extent. The healthcare logistics research field is situated somewhere between nascent theory and intermediate theory, leaning toward intermediate theory as illustrated in Figure 3.1. Extant literature therefore provides a foundation on which to build future research, albeit a narrow one.

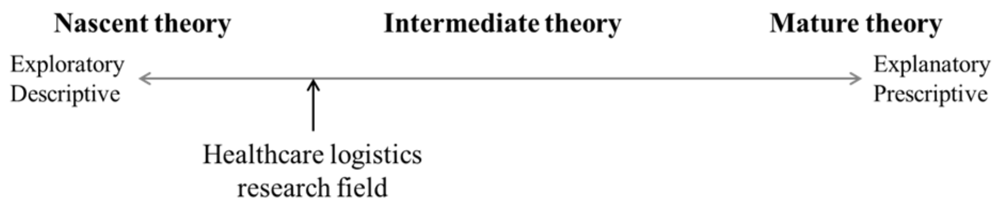

Figure 3.1. Maturity of the healthcare logistics research field. Adapted from (Åhlström, 2016) and (Edmondson and McManus, 2007).

The maturity of the research field is reflected in the overall research question (RQ) posed in this thesis. The overall RQ is the following meta-RQ:

Meta-RQ: *How can hospitals improve their logistical processes to ensure that the process design and performance fit the needs and preferences of a hospital?*

Despite the healthcare logistics research field being somewhat new, the field has developed further than the nascent stage in the direction of the intermediate stage, where more explanatory and prescriptive research is suitable. The meta-RQ is therefore somewhat explanatory and prescriptive as it is a “how” question.

Focusing the meta-RQ. How hospitals can improve their logistics processes is investigated in terms of the four types of interventions, which were identified in the literature review: 1) BPM, i.e. changes to process steps, 2) logistics and SCM interventions, 3) technological interventions, and 4) organizational interventions. Furthermore, improvement of logistics processes is reflected in the meta-RQ in terms of the "needs and preferences of the hospital". This specific formulation of the meta-RQ was chosen to reflect the fact that different hospitals may have different strategies, focus areas, political environments and social structures in which they operate and consequently different needs and preferences. As mentioned in the Introduction, costs and quality of service are major concerns in the healthcare industry and motivate this study. The needs and preferences of hospitals are therefore likely to reflect cost and quality aspects. The cost and quality aspects of improving healthcare logistics processes are investigated in this study in terms of improving the *efficiency* and *effectiveness* of processes. Efficiency is input oriented and concerned with the economic use of resources. Effectiveness is output oriented and concerned with achieving goals (Mentzer and Konrad, 1991; Neely et al., 2005). Simply stated, efficiency is "doing things right" and effectiveness is "doing the right thing". Thus the cost aspect is reflected in *efficiency* and the quality aspect is reflected in *effectiveness*, which in turn reflect performance (Mentzer and Konrad, 1991; Neely et al., 2005).

Breaking down the meta-RQ. The meta-RQ consists of three RQs and underlying sub-questions (SQs), which are presented in three boxes in the following. RQ1 and the underlying SQs are listed in the following:

RQ1: *How can healthcare logistics processes be characterized in terms of challenges and composite design elements?*

1.1 What are the challenges specific to healthcare logistics processes?

1.2 Which interventions can hospitals implement to improve healthcare logistics processes?

1.3 Which benefits can be identified for interventions and approaches for improving healthcare logistics processes?

1.4 What are the contingent factors that determine when different interventions and approaches for improving healthcare logistics processes are recommendable?

RQ2 and the underlying SQs are listed in the following:

> ***RQ2:*** *Which factors should decision makers consider when improving healthcare logistics processes?*
>
> **2.1** Which factors impact the design of healthcare logistics processes?
>
> **2.2** How do impact factors affect the design of healthcare logistics processes?

RQ3 and the underlying SQs are formulated as follows:

> ***RQ3:*** *How can the identified impact factors be used to assess healthcare logistics systems?*
>
> **3.1** How can the identified impact factors be used to measure and benchmark the performance of healthcare logistics processes?
>
> **3.2** How can healthcare logistics processes be assessed to ensure a solution that best fits the preferences of a hospital?

Simply put, RQ1 considers "how could be improved?" in terms of composite design elements, RQ2 "why this improvement?" as determined by impact factors, and RQ3 "how should be improved?" based on an assessment. This progression of RQs follows a natural order of making an improvement decision. The descriptive nature of RQ1 and explanatory nature of RQ2 fit well with the maturity of the field. RQ3 is of a more prescriptive nature and is enabled by the preceding descriptive and prescriptive RQs. Furthermore, the predictive claims of the "could" and "should" questions is what makes this research useful to managers (Wacker, 1998).

Figure 3.2 illustrates the hierarchy of research questions and the link between papers and the research questions of this thesis, i.e. how the overall meta-RQ trickles down into the research questions investigated in each paper. The parentheses indicate the paper where the investigated research question was posed and the question number in that paper.

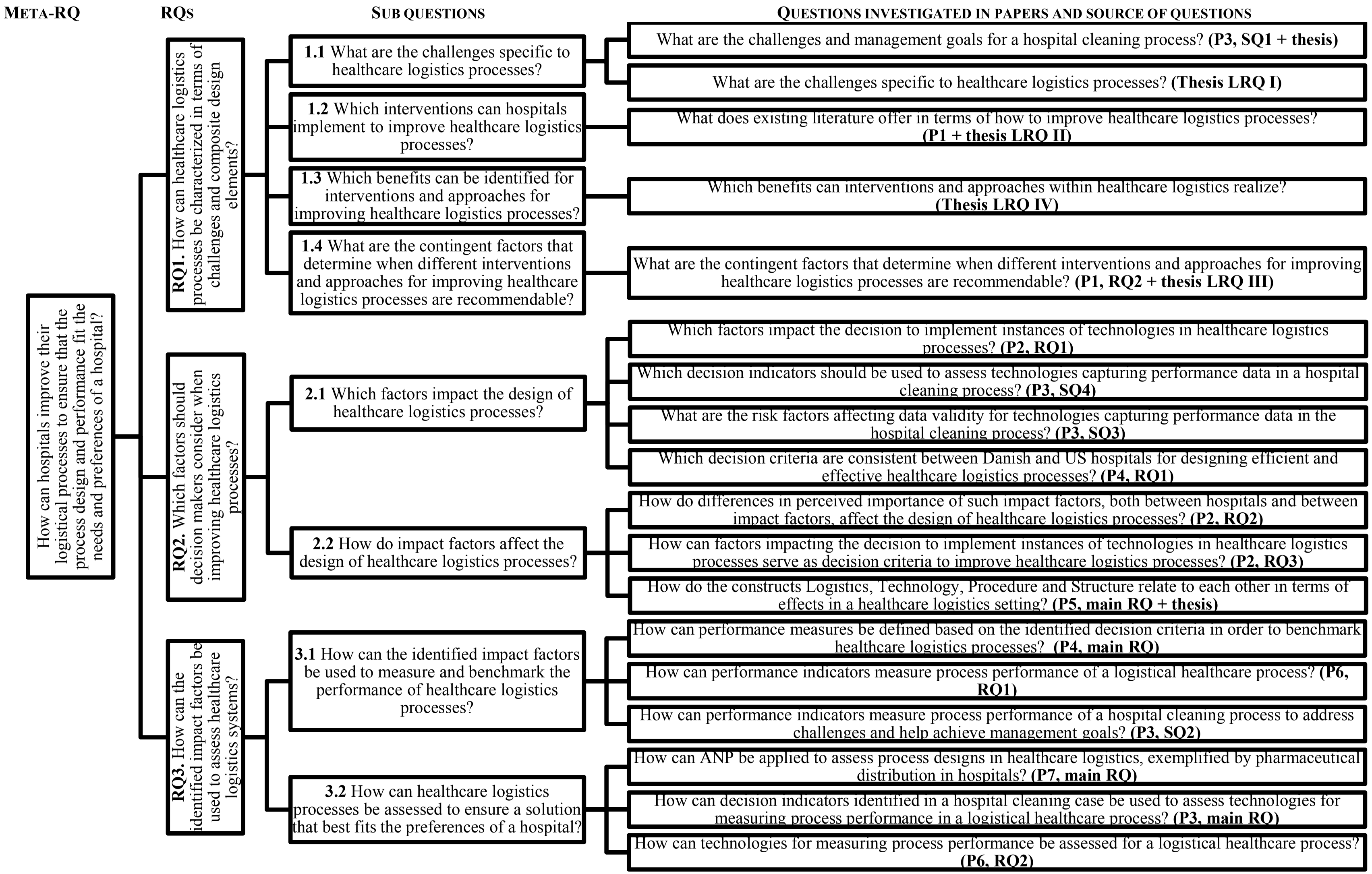

Figure 3.2. Link between papers and research questions

3.3 RESEARCH OBJECTIVES

Research objectives describe the actions taken to answer the research questions. Moreover, the objective of a study indicates how the research aim is achieved. The overall objective of the research conducted in this study is as follows:

Overall research objective: *Provide theoretical and empirical evidence to determine how healthcare logistics processes can and should be improved.*

The overall research objective is broken down to the following actions undertaken to reach the overall research objective and answering the RQs:

Actions undertaken to reach overall research objective:

- Search literature to determine the state of healthcare logistics research
- Identify avenues for future research based on the literature review
- Identify possible methods for assessing the design and performance of healthcare logistics processes
- Determine the theoretical area of research for this study
- Identify suitable common and best practice hospitals for investigation
- Identify relevant processes for investigation
- Analyze each case study process to answer research questions
- Compare Danish and US logistics processes in hospitals
- Compare the different investigated healthcare logistics process types
- Identify differences and similarities between process types and country settings

The overall research objective and specific actions are reflected in the analysis of this study.

3.4 OVERALL CONSTRUCTS OF THE THESIS

At an overall level, the constructs investigated in this paper are 1) possible improvement interventions and 2) the decision to implement these interventions. The interventions alter the process design and are implemented to improve the process. The possible improvement interventions each relate to procedures, logistics, technologies and organizational structure as identified in the literature review. The identified impact factors, which serve as decision criteria, influence the decision to implement the possible improvement interventions and thus have a mediating effect on the decision process. A variation of the links between the constructs depicted in Figure 3.3 is applied as an a priori coding scheme and will be discussed in the Analysis section.

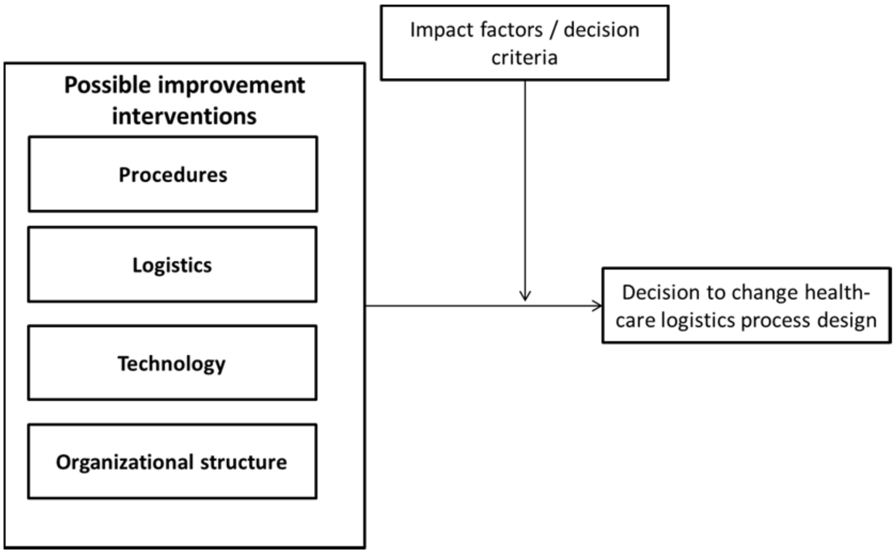

Figure 3.3. Constructs investigated in the thesis

3.5 Theory building in OM and SCM

This PhD project falls within the fields of OM and SCM, in particular logistics management. In the following, this thesis is positioned in an OM/SCM/logistics management context and theory building within this field is discussed.

3.5.1 Operations management and supply chain management

According to Karlsson (2016), operations can be defined as a transformation activity, which transforms resources and converts inputs into outputs, i.e. goods or services. Managing these operations, i.e. operations management, is viewed as a cross disciplinary and applied field with managerial characteristics. Designing operations systems involves the planning of information, materials flows, layouts and technologies for transformation in addition to the design of the organization and processes (Karlsson, 2016). In this study, the design of logistics processes includes technological interventions and process interventions and implications for human resources and the structure of the organization. In the following, theory building within an OM and SCM context and the implications for this study are discussed.

Gammelgaard (2004) suggests that there are three “schools” in logistics research; the *analytical school*, the *systems school* and the *actors school*, but that exemplary cases have only been found within the analytical school and the systems school. This study falls within the systems school in which theory is context specific and where it is necessary to analyze and compare cases to develop new knowledge. Furthermore, the systems approach is pragmatic in the sense that it seeks a practice oriented solution for a problem (Gammelgaard, 2004).

3.5.2 Theory building

According to Wacker, theory consists of four composites. He outlines four steps for "good" theory building, although these might not occur sequentially (Wacker, 1998). The composites of theory and the steps of good theory building are found in Table 3.1 together with the application in this study.

Table 3.1. Theory building in this study – adapted from (Wacker, 1998).

Composites of a theory	Good theory building	Application and theory building in this study
Conceptual definitions	Defining variables	Variables are defined based on literature and case studies.
Domain limitation	Limiting the domain	The domain has been limited to healthcare logistics processes and to activities mainly within hospitals.
Relationship building	Relationship (model) building	A framework is developed containing interventions, impact factors/decision criteria, contingent factors and outcomes.
Predictions	Theory predictions and empirical support	Rather than predictions, explanations are provided, in accordance with the critical realism standpoint.

In good theory building, systematic similarities, i.e. patterns, are more important than descriptive differences (Wacker, 1998). Differences will occur between the investigated case studies, but the focus in this study will be on identifying similar patterns across case studies. By testing a theory in a new environment or time period, theory building extends the theory to new domains. Accordingly, this study tests theory for different process types and different country settings. Furthermore, integrating existing theory in building theoretical relationships increases the abstraction level of the theory. The literature review of this study therefore plays an important role in terms of generalizing findings. A 2011 paper by Choi and Wacker reviewing extant literature within OM and SCM offers guidelines for future theory building in the field. Similar to the 1998 paper by Wacker, they suggest that the boundaries of a study should be clearly delineated and that new theory should build on existing literature. Domain limitations of this study are found in the Domain limitation section of this chapter. Furthermore, the authors argue that multiple theoretical perspectives should be integrated to explain an issue and possibly challenge the dominant paradigm (Choi and Wacker, 2011). As indicated in the literature review, different theoretical streams of literature are integrated in this study: BPM, logistics and SCM, technology assessment and justification, and human factors and organizational management.

Wacker argues that theory building research can be classified as either analytical research or empirical research and further be divided into six categories. This study falls within the classification *empirical research*, specifically the sub-category *empirical case study*. The empirical case study, like all six sub-categories of research types, is important for OM theory building. Empirical case studies can propose new theories by testing and developing relationships between variables. Empirical research can be refuted based on internal inconsistency (Wacker, 1998). The justification and use of the case study as research design in this thesis is described in the Research Design section.

3.5.3 Domain limitation

The domain of this study is limited to logistical processes within the boundaries of a hospital, mainly those related to materials management, but also to some extent the distribution of services. The transport and logistics of patients is not considered. The focus on the internal processes of hospital logistics excludes most of the healthcare supply chain. Ties to the external supply chain are only considered if there are implications for the activities of the internal supply chain. Procurement activities and collaboration aspects are not considered, only physical replenishment activities.

Interventions relating to either one of the following types are considered: 1) BPM, i.e. changes to process steps, 2) SCM and logistics interventions, 3) technological interventions, and 4) organizational interventions. Other types of interventions are not considered in this study.

3.6 Case study as research design

The research design chosen for this research project is the case study. In the following, a justification of the case study as research design, the selection of case studies and arguments for discarding other research designs are provided.

3.6.1 Why case study as research design

A research design should reflect the nature of the research questions, e.g. (Ellram, 1996; Karlsson, 2016; Yin, 2014). This study is suitable for case study research because 1) the overall research question is a "how" question (Benbasat et al., 1987; Yin, 2014), 2) the study does not require control of behavioral events, 3) the research questions focus on contemporary events (Yin, 2014), and 4) the studied phenomenon can be investigated in its natural setting (Benbasat et al., 1987). Moreover, lack of maturity in the research field as revealed by the literature review makes the study suitable for case studies, e.g. (Åhlström, 2016). Finally, the subject of investigation will affect the suitability of a research method. Thus, Yin (2014) defines a case study as "a study that investigates a contemporary phenomenon (the 'case') in depth and in its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident". The phenomenon investigated in this study is the logistics process, more precisely the improvement of logistics processes. The context in which this phenomenon is investigated is a healthcare context, particularly that of a hospital. It is important for the purpose of this study to understand the phenomenon in its context of a healthcare setting, making the case study a suitable research method.

One of the benefits of case research is the increased possibility of identifying cause and effect (Voss et al., 2016). Eisenhardt argues that the strengths of case study research are the likelihood of generating novel theory, that emergent theory is testable, and that resulting theory is empirically valid. She moves on to identifying some weaknesses of case study research. One weakness is the overwhelming amount of data, which can lead to overly complex theories. Furthermore, case study research may lead to findings that are too narrow in their application (Eisenhardt, 1989).

3.6.2 Selecting the case studies

When theory building is based on case studies, case sampling should rely on theoretical sampling instead of random sampling. In theoretical sampling, cases are selected based on the likelihood of the replication or extension of an emergent theory (Eisenhardt, 1989). Case studies are selected based on the principle of literal replication, which predicts similar results, rather than theoretical replication, which produces contrary results (Voss et al., 2016; Yin, 2014). In this study, factors impacting the design of healthcare logistics processes are investigated for different hospitals, processes and country settings to identify the impact factors that apply across cases. It was expected that there would be some overlap between the factors identified across process types and countries. However, some differences were expected between the Danish and US hospitals, which will be presented in the Results.

The Danish case study hospitals were chosen because they are located within the same hospital region and therefore are subject to the same governance structure and budgetary limitations. The main case hospital provided funding and access to data. Access to the other Danish hospitals was achieved through the main case hospital.

The US hospital was chosen because it is considered one of the best hospitals in the US. Compared to the Danish case study hospitals, which are all public, the US hospital is owned by a non-profit organization and is not in the same way limited financially.

Each case study conducted during this research project focuses on a specific process. Three case studies were conducted in Denmark:

A. A multiple case study of the bed logistics process

B. A single case study of the hospital cleaning process

C. A single case study of the pharmaceutical distribution process

In the US hospital, the following two case studies were conducted:

D. A single case study of the bed logistics process

E. A single case study of the pharmaceutical distribution process

A multiple case study was chosen as the design for the first case study for two reasons. First, to gain a thorough understanding of what a healthcare logistics process is, in this case exemplified by the bed logistics process. Second, to ensure a solid foundation and initial framework that applies to more than a single hospital, i.e. ensuring that the believed "common case" is in fact the common case.

A separate case study considering the hospital cleaning process was not conducted for the US hospital. This was partly due to time constraints and the fact that the bed logistics case study and pharmaceutical distribution case study had provided more interesting results for the Danish hospitals. However, interviews and observations were made for the cleaning process as part of the bed logistics process in the US hospital, which was also done for the Danish bed logistics case study. Thus, to some extent, the hospital cleaning process is embedded in the bed logistics case study for the US hospital.

The purpose of the US case study hospital was to learn from what was expected to be best practice in terms of designing high performing healthcare logistics processes. Both Danish and US case studies showed room for improvement, but the US case studies revealed processes that were more mature and superior in terms of process performance.

For choosing an appropriate number of cases, Eisenhardt suggests using between four to ten cases (Eisenhardt, 1989). Accordingly, four single case studies and one multiple case study were conducted for this study. Another way of viewing the case studies is as a single case study of the hospital cleaning process and two multiple case studies, i.e. a multiple case study of the bed logistics process and a multiple case study of the pharmaceutical distribution process. This study could even be viewed as one multiple case study consisting of nine cases, i.e. five Danish bed logistics cases, one US bed logistics case, one Danish hospital cleaning case, one Danish pharmaceutical distribution case and one US pharmaceutical distribution case. Case studies A to E are treated separately before comparisons are made between selections of cases, i.e. Danish cases, US cases, bed logistics cases, the hospital cleaning case and pharmaceutical distribution cases, to finally compare across all cases.

3.6.3 Boundaries of cases and unit of analysis

The boundaries of the cases follow the delimitations of this study. The focus is on internal logistical processes of hospitals. The hospital can be viewed as an open system which interacts with other and larger systems, e.g. the external supply chain. First tier agents in the supply chain are considered for some cases, e.g. the regional warehouse in case C, but are not the main focus of the study. The unit of analysis is the healthcare logistics process. Healthcare logistics processes are exemplified in this study by the three types of investigated processes:

1) The bed logistics process
2) The hospital cleaning process
3) The pharmaceutical distribution process

These particular processes were chosen as subjects of investigation based on discussions with the primary case hospital, taking their focus and needs into consideration as well as the potential for providing a research outcome. The hospital cleaning process may not seem like a logistics process at first glance, but could be viewed as the distribution of services. As such, hospital cleaning is often a task undertaken by the logistics department in a hospital, e.g. (Aptel et al., 2009; Pan and Pokharel, 2007). Each process type will be described in detail in the Results.

3.6.4 THEORY BUILDING BASED ON CASE STUDY RESEARCH

Case study research is important for the advancement of the OM field (Voss et al., 2016; Wacker, 1998). Accordingly, the research field has experienced an increase in qualitative case studies in recent years (Barratt et al., 2011). Case study research has been accused of not being rigorous research. However, several authors argue and demonstrate that it is possible to conduct rigorous case research and to build theory based on case studies within OM, e.g. (McCutcheon and Meredith, 1993; Meredith, 1998; Stuart et al., 2002). Furthermore, the usefulness of case studies in logistics research in particular has been demonstrated by Ellram (1996).

Case research seeks to understand a phenomenon by utilizing both qualitative and quantitative methods (Meredith, 1998). As noted in the literature review, the most prevalent research method applied in the reviewed healthcare logistics papers is case study research. Case study research can be used for exploration, theory building, theory testing, and theory extension/refinement (Voss et al., 2016). Although the maturity level of the research field is low, a small literature base does exist. The purpose of this study therefore fits well with theory building.

Case studies are excellent for theory building and for providing detailed explanations of best practices (Ellram, 1996), both of which will be utilized in this study. In theory building, key constructs are identified and relationships identified between variables (Voss et al., 2016). It is necessary (Miles et al., 2014), or at least helpful, to have some indication of the constructs (Eisenhardt, 1989). The constructs Logistics, Technology, Procedure and Structure are used a priori for coding data. These four constructs are variations of the themes identified in the literature review and were, in addition, identified in the previous study by Jørgensen (Jørgensen, 2013). For theory building purposes, the Discussion compares the findings to existing theory (Eisenhardt, 1989).

A limited number of focused case studies were conducted, i.e. in Denmark, and compared to best-in-class case studies, i.e. in a US hospital. This approach is similar to an inductive study (Voss et al., 2016). Furthermore, the underlying variables for each construct are identified based on the case studies. The variables are the underlying impact factors, which can differ in amount and type, i.e. impact factors may differ in importance and some impact factors may not apply under certain circumstances.

The selection of cases is an important aspect of theory building. Furthermore, theory building research typically combines multiple data collection methods (Eisenhardt, 1989). Cases are therefore carefully selected and mixed methods are applied. Mixed methods is explained in greater detail later in this chapter. When a similar pattern is found across several cases, the findings are stronger and better grounded in empirical evidence. In case of conflicting patterns, deeper probing into the evidence may provide explanations of such a difference or simply indicate randomness (Eisenhardt, 1989). Patterns are therefore identified within and across cases for this study.

Stuart et al. argue that valid criticisms of case study research include 1) the risk of becoming a collection of anecdotes, 2) the overwhelming amount of data and 3) the risk of long narratives. Providing a chain of evidence for part of the data may offer a way to convince the reader that all data was treated similarly (Stuart et al., 2002). Some of the main challenges posed by case research have also been addressed in the 2007 paper by Eisenhardt and Graebner. These challenges include theoretical sampling of cases, dealing with rich data from interviews, presenting empirical evidence, and writing up the emergent theory. They argue that these challenges can be addressed through the careful justification of theory building, theoretical sampling of cases, limiting informant bias, providing a rich representation of data, and clearly stating theoretical arguments (Eisenhardt and Graebner, 2007). Finally, the issue of generalizability is one of the most common criticisms of case study research. Ketokivi and Choi argue that case research is *situationally grounded* but at the same time seeks *a sense of generality* (Ketokivi and Choi, 2014). They propose that the rigor of case research can be ensured by paying attention to contextual idiosyncrasy already in the data collection stage and by providing transparent reasoning.

3.6.5 Excluded research methods

Selecting the case study as research design means actively deciding not to use other possible research methods. In the following, the justification for discarding other research methods is provided.

Simulation. The previous study by Jørgensen (2013), upon which this study builds, is also a case study but focuses on simulation. To move beyond this previous study, simulation was therefore discarded for this research project.

Survey. Although this study contains a small survey where respondents assign values to impact factors, the sample is limited and it is not possible to provide statistically significant conclusions. A larger sample size would be needed for a statistical analysis. Furthermore, surveys and statistical analyses are better suited for more mature research fields (Åhlström, 2016), and as the literature review revealed, the field of healthcare logistics is still in its early stages of development as a research field.

Mathematical modelling. Several studies have been conducted in the field of healthcare logistics which apply mathematical modelling (Beliën and Forcé, 2012; Utley et al., 2003; Volland et al., 2016). Mathematical modelling is not suitable for all the RQs investigated in this study but is included to a limited extent through the application of the analytic network process (ANP) method.

Action research. Applying action research to the case studies would require that the case study hospitals be willing to make changes during the course of the project, which was not possible in this case. Action research was therefore discarded as a research method for this study.

The presented arguments show that although other research designs could have been used for this study, the case study research design provides the best fit with the research questions, maturity of the field, and circumstances and possibilities within the case study organization.

3.7 MIXED METHODS RESEARCH

Edmondson and McManus (2007) argue that the state of prior theory and research determine the type of data to collect and the method for collecting data. For a nascent research field, qualitative data is obtained through interviews, observations and documents, whereas for an intermediate research field, both qualitative and quantitative data is collected through interviews, observations and site material (Edmondson and McManus, 2007). To ensure methodological fit with the maturity of the field, this study is therefore based on mixed methods research, i.e. qualitative and quantitative data. Mixed methods research draws on both qualitative and quantitative data and research methods. Johnson et al. define mixed methods research as follows:

> Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches […] for the broad purposes of breadth and depth of understanding and corroboration. (Johnson et al., 2007)

Creswell and Plano Clark (2011, p.8) provide the following list of situations that warrant a mixed methods research approach:

- A single method is not sufficient
- Results need to be explained
- Exploratory findings need to be generalized
- A second method is needed to enhance a primary method
- A theoretical stance needs to be employed
- An overall research objective can be best addressed with multiple phases or projects

The primary reason for adopting a mixed methods approach in this study is the enhancement of the primary method by applying a second method, i.e. the quantitative data and analysis enhances the findings of the qualitative data and analysis.

A mixed methods approach begins with a choice of either quantitative or qualitative research and then shifts between the two approaches to gain new insights (Golicic and Davis, 2012). To gain a deeper understanding of healthcare logistics processes and their improvement potential, this study starts with a qualitative approach and moves on to a quantitative approach. Thus, the qualitative and quantitative methods are applied in sequence rather than concurrently (Davis et al., 2011). Johnson et al. distinguish between three types of mixed methods: 1) qualitatively dominant, 2) quantitatively dominant and 3) equal status (Johnson et al., 2007). The mixed methods approach adopted in this thesis is qualitatively dominated. This unequal and sequential approach is what Davis et al. refer to as *initiation* (Davis et al., 2011), the purpose of which is to let an initial study inform a second study (Golicic and Davis, 2012). This is what Creswell and Plano Clark denote *the exploratory sequential design* (Creswell and Plano Clark, 2011).

The application of mixed methods research in the field of SCM is limited, but has increased in recent years (Golicic and Davis, 2012). SCM being a relatively new field combined with the complexity of the field makes mixed methods research suitable for SCM research because of the new and complex phenomena to be investigated. Thus, Golicic and Davis argue that mixed methods research has the potential for advancing the theoretical field of SCM in a way that is not possible through the application of single research methods (Golicic and Davis, 2012).

3.7.1 Benefits and challenges of mixed methods research

The main benefits and challenges of mixed methods research are discussed in the following. In terms of benefits, mixed methods research offers the strengths of both qualitative and quantitative research approaches, thus complementing the weaknesses of each research approach (Creswell and Plano Clark, 2011). The use of both qualitative and quantitative evidence can also create synergies (Eisenhardt, 1989). The use of different types of data and methods enables triangulation and provides richer and stronger evidence to support the findings of a study (Creswell and Plano Clark, 2011; Johnson et al., 2007; Yin, 2014). Furthermore, mixed methods research may lead to answers and explanations that are more meaningful, provide a better understanding and a fuller picture (Johnson et al., 2007), and possibly brings the research closer to the truth (Sechrest and Sidani, 1995). Moreover, mixed methods research may answer more complex research questions that cannot be answered by applying a single method (Creswell and Plano Clark, 2011; Yin, 2014). Finally, a more pragmatic and unrestrictive use of research methods is offered, which could potentially reconcile qualitative and quantitative researchers (Creswell and Plano Clark, 2011).

One of the challenges of mixed methods research is the mastery of several types of research methods required by the researcher (Creswell and Plano Clark, 2011). I.e. qualitative and quantitative techniques require different skills. This study mainly builds on qualitative data, thus data was mostly collected through interviews and observations. During the course of this study, 63 interviews and 17 observation session were carried out. The quantitative data is limited by comparison, consisting of a few quantitative files, e.g. the number of beds cleaned in a hospital, but mainly the ranking of impact factors as decision criteria. The ranking of decision criteria was based on respondents assigning a value on a 0-10 scale according to the importance of the decision criteria for improving healthcare logistics processes. The quantitative analysis conducted does not involve elaborate quantitative techniques, but is almost entirely limited to calculating averages and standard deviations. The most technically difficult method used in this study is the ANP method. However, software was used to compute the results of the ANP model and did not require sophisticated quantitative analytical skills. Data gathering and analysis therefore mostly required skills within the qualitative domain and was limited for the quantitative domain.

Another challenge with mixed methods research is time and resources (Creswell and Plano Clark, 2011). More time is needed for data collection, analysis and interpretation, which is reflected in the number of conducted case studies.

A final challenge noted by Creswell and Plano Clark (2011) is the question of convincing others of the rigor of mixed methods research. Thus, although mixed methods were applied and described in the papers, the term *mixed methods research* was not explicitly used in any of the paper titles or manuscripts. In the following, the application of mixed methods in this research project is presented and discussed.

3.7.2 Types of qualitative data gathered

The qualitative data gathered consists of documents, interviews and observations. The documents were provided by the hospitals in addition to a regional pharmaceutical warehouse. All interviews were conducted by the author and the observations were conducted by the author during scheduled sessions.

3.7.3 Types of quantitative data gathered

Quantitative data gathered in this study consists of files containing numeric data, e.g. number of beds cleaned, number of emergency department beds, or number of rooms distributed across a hospital. The bulk of quantitative data used in this study relates to respondents ranking decision criteria on a 0-10 scale. In one instance, quantitative data consists of a pairwise quantitative comparisons of decision criteria.

3.7.4 Ranking of decision criteria

The identified impact factors were ranked as decision criteria according to the importance in terms of improving healthcare logistics processes. The decision criteria were ranked based on a ten point Likert-like scale. Likert scales typically offer five or seven points, but in this case, a ten point scale was used. A “10” indicates strong agreement that the impact factor is an important decision criterion for improving healthcare logistics processes. A “0” indicates that the impact factor has no relevance as a decision criterion. A “1” indicates that the criterion has extremely limited and almost no relevance and a “5” indicates that the impact factor is of medium relevance. Originally, the scale was from 1-10, but as certain decision criteria in some cases were perceived as not relevant, the option of “0” was added to the scale.

3.7.5 The Analytic Network Process (ANP) method

The ANP method was used in case C. ANP is a multi-criteria decision analysis method for quantitatively prioritizing possible solutions based on a set of criteria. ANP breaks down a complex problem to its constituent components and prioritizes alternatives based on a pairwise comparison of these components. ANP allows for a quantitative assessment of both qualitative and quantitative criteria (Saaty, 2004a). The pairwise comparisons are either based on individual or group judgments or actual measures (Saaty and Vargas, 2006).

ANP is a generalization of the analytic hierarchy process (AHP) method, which is a special case of ANP (Saaty and Vargas, 2006; Saaty, 1990). AHP is a linear hierarchy consisting of a goal, criteria and alternatives, which are not interdependent. ANP is a non-linear network, which accounts for an inner dependence within a cluster of elements and an outer dependence between clusters (Saaty, 2004a). AHP is easier to apply, but requires independence between parameters, which is not required for the ANP method. The ANP method therefore takes feedback loops into account (Saaty and Vargas, 2006). For this reason, the ANP method was chosen. For both the ANP and AHP methods, the underlying assumption is that it is easier for people to make pairwise comparisons rather than comparing all decision criteria at once. Based on these pairwise assessments, it is then possible to provide an overall prioritization of alternatives (Saaty and Vargas, 2006; Saaty, 2004a, 2004b).

The alternatives are pairwise compared with respect to each criterion. To assess how much more important one criterion is to another in the pairwise comparison, a scale of intensity is utilized. The most dominant element is assigned a value of 1-9 according to the scale in Table 3.2 and the lesser dominant element is assigned the reciprocal value.

Based on the pairwise comparisons, a prioritization of alternatives is computed by using the software Super Decisions (www.superdecisions.com, 2016). For a more detailed description of the theory, an abundance of literature is available, e.g. (Saaty and Vargas, 2006; Saaty, 2004a).

Table 3.2. Scale for quantitative comparison. Sources: (Saaty and Vargas, 2006; Saaty, 2004a).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another.
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another.
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.

In case C, ANP was applied to the framework of impact factors to enable the ranking of possible solutions for the distribution of pharmaceutical products. Furthermore, the application of the ANP method to the developed framework enabled the ranking of decision criteria. The deputy logistics manager in the Danish hospital provided pairwise comparisons of decision criteria and alternatives based on own judgments. The assigned values from the pairwise comparisons were entered into the Super Decisions software (www.superdecisions.com, 2016), and the computed results can be found in the Results chapter. The links between the clusters in the ANP model are found in Figure 3.4. The links reflected in the ANP model were identified in case A (P5), and validated for case C (P7).

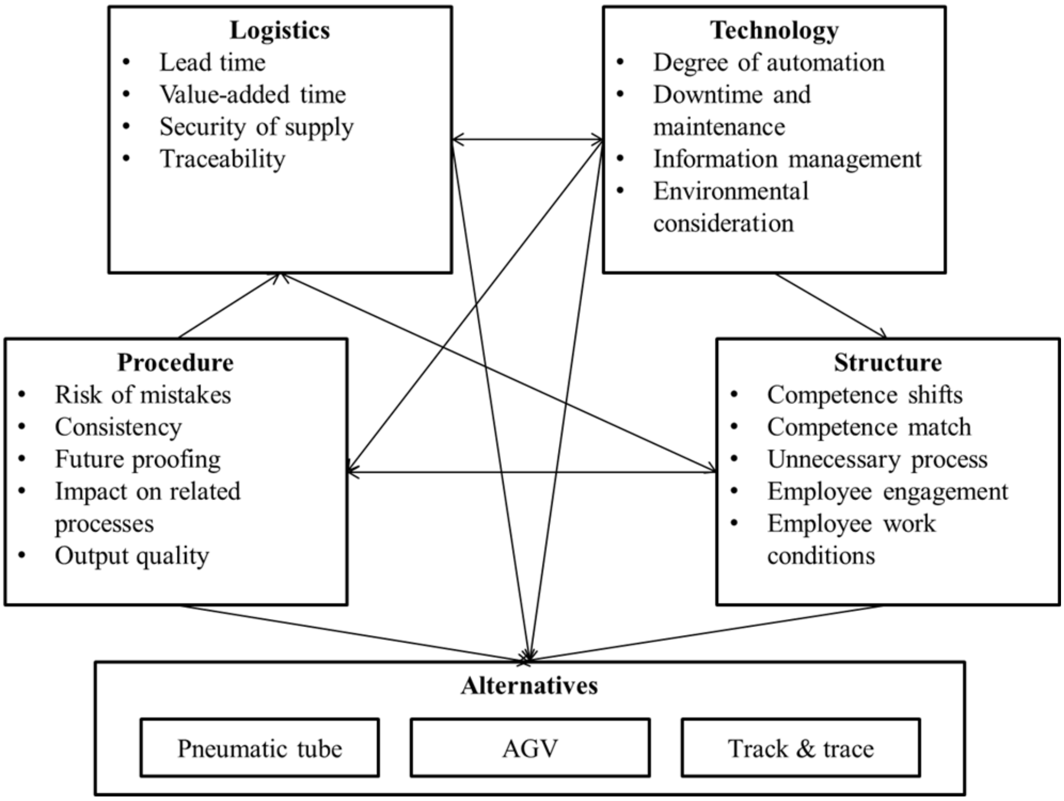

Figure 3.4. Illustration of ANP model as illustrated in Super Decisions software

For simplicity and to make Figure 3.4 more easily comprehensible, the links between the underlying criteria within each of the clusters, i.e. Logistics, Technology, Structure, Procedure and Alternatives, are not illustrated here.

3.7.6 Quantitative and qualitative assessment

The developed framework serves as a decision tool for improving healthcare logistics processes. The tool can be applied to enable either a quantitative, qualitative or combined assessment of interventions and consequent process designs. E.g. applying the ANP method to the developed framework would allow for a quantitative assessment of different process solutions, whereas a descriptive report of the elements of the framework would allow for a qualitative comparison of possible process solutions.

3.8 Data collection

Case studies rely on multiple sources of evidence to enable triangulation (Yin, 2014). For this study, different types of data were collected by adopting different data collection strategies. Furthermore, data was collected from different hospitals and organizational units. Data was mainly collected from the funding Danish hospital and a US hospital. For case study A, data was gathered from the funding hospital and four other hospitals. For case study B, data was mainly gathered from the primary, i.e. funding, hospital and limited data was gathered from another Danish hospital for comparison. For case study C, data was gathered from the primary hospital and limited data was gathered from another Danish hospital for comparison. Although case study B and C include data from other hospitals, the data from these hospitals was not sufficient to constitute dual case studies, but did provide a broader perspective on the cases. For the US case studies, i.e. case study D and E, data was gathered from a single US hospital.

3.8.1 DATA COLLECTION STAGES

Data was collected between February 2014 and February 2016. Figure 3.5 illustrates the timeline for data collection pertaining to each case study.

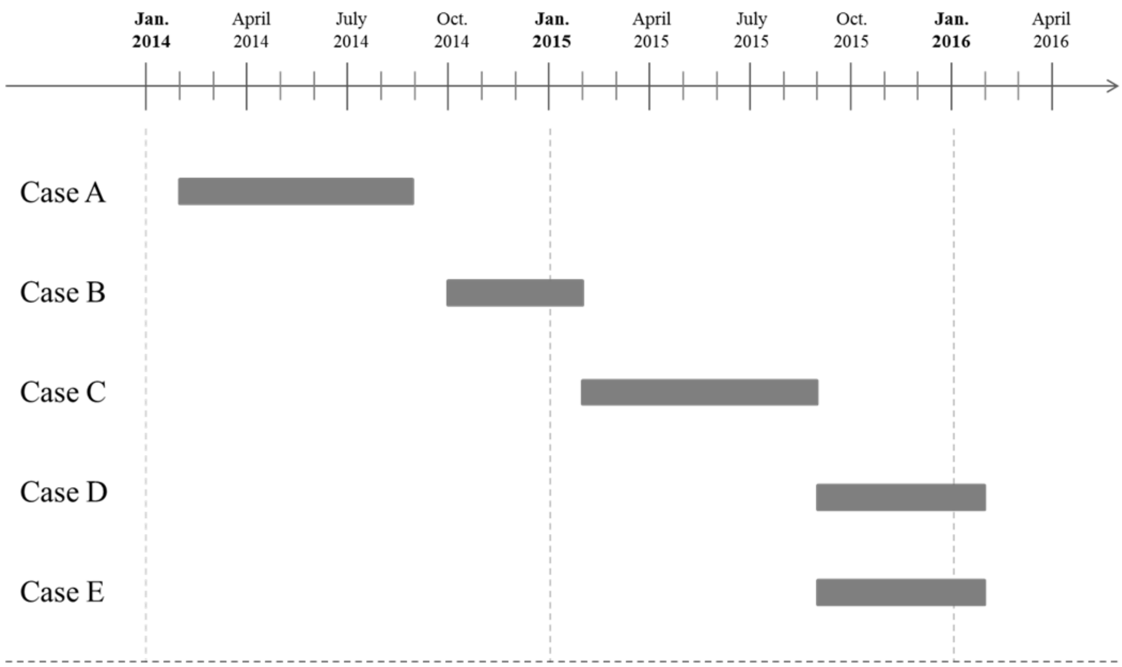

Figure 3.5. Timeline of data collection for case studies

The comparative case studies for Denmark and the US, i.e. the case studies investigating the bed logistics process and the pharmaceutical distribution process, all follow the same overall data collection stages:

1) A round of semi-structured interviews and observations
2) A validation and factor ranking round of either structured interviews or a survey

The bed logistics process investigated in Denmark, i.e. case A, includes an extra preliminary phase because it was the first case study investigated for the PhD project. A preliminary understanding of healthcare logistics processes was therefore necessary.

3.8.2 Guided data collection

The research questions help identify relevant information to be collected (Yin, 2014)(p.30). Furthermore, case study protocols were used to guide the collection of data for each case study. The case protocol guidelines provided by Yin include four aspects: 1) a case study overview, 2) data collection procedures, 3) data collection questions and 4) a guide for the case study report (Yin, 2014)(p.84). The case study protocols for this project included 1) an overview of people to be interviewed, including their roles, responsibilities and contact details, 2) preparations necessary prior to the interview/observation, 3) background information to inform respondents, 4) purpose of interview/observation, 5) interview questions and interview question categories, 6) particular events, items or occurrences to document for observations, and 7) how to report data. An example of an interview guide is found in Appendix B and an example of an observation guide is found in Appendix C as part of the case study protocol. Moreover, one of the features of case study research is that data collection and data analysis is guided by theory (Yin, 2014). Data is therefore coded according to previously developed constructs, which will be discussed in the section regarding coding of qualitative data.

3.8.3 Documenting data

All field work was conducted by the author of the thesis. During field work, field notes were taken to document interviews and observations. Directly after the field work was carried out, the notes were documented electronically and elaborated while fresh in mind. The notes were then rearranged according to the objectives and logical themes to provide a logical storyline.

3.8.4 Interviews

Interviewees were selected based on their knowledge about the case study process in addition to their knowledge about and access to relevant process data. Open interviews with a flexible agenda were conducted for the preliminary stage of case study A. The semi-structured interviews conducted for the case studies were structured based on previous data and findings. Structured interviews were constructed similar to the conducted survey with a rigid set of questions and a specific set of possible answers. The posed interview questions relate to the research questions and mainly consider 1) challenges in the process, 2) reasons for implementing interventions such as changes to process steps and the implementation of technologies, 3) reasons for interventions failing, and 4) performance measurement. An example of an interview guide with inherent research questions for the semi-structured interview can be found in Appendix B. The format of the structured interviews follows the structure of the survey, an example of which can be found in Appendix D. The interviews lasted between 30-90 minutes depending on the subject and interviewee.

3.8.5 Observations

Observations were carried out for each case study to learn about the process. During the observations, some interaction would occur to understand what was happening and to obtain the opinion of the activities performed by the employee. In some cases, the observations were direct observations without interaction but for most cases some interaction would occur with the employees, making the observations participant-observations. Observation sessions lasted between 30-60 minutes depending on the activity observed.

3.8.6 Documents

Different types of documents were obtained for the case studies. Documents providing insights into process performance, standard operating procedures (SOPs), volumes of activities, and guidelines for operations, were obtained to gain an understanding of the investigated processes. Tables 3.3 to 3.7 include lists of the documents obtained for each case study.

3.8.7 Survey and structured interviews

For the validation and ranking round of data collection, either a structured interview was conducted or an email survey sent, depending on what was possible for the respondent. This type of interview is what Yin refers to as a "survey interview", and this nested arrangement of survey and case study is referred to as "a survey within a case study" (Yin, 2014). For case B, the validation was quantitative instead of qualitative. The respondents were chosen based on the role as decision makers in the investigated process. The structured interviews and survey followed the same structure, which can be found in Appendix D.

3.8.8 Data collection case study A: Bed logistics in Denmark

Data was collected from five Danish hospitals for a multiple case study of the bed logistics process. Data collection consisted of three stages: 1) a preliminary stage, 2) a round of semi-structured interviews, and 3) a round of structured interviews. Each of the stages will be described in the following.

Preliminary stage. The preliminary stage served as a type of pilot study at the primary case hospital, consisting of twelve open interviews, four sessions of direct observations of each stage of the bed logistics process in addition to observing the conveyor belt for transport between buildings. Furthermore, documents containing process data and standard operating procedures were obtained. The purpose of this preliminary data gathering stage was to gain an understanding of the bed logistics process and identify challenges and improvement opportunities of the bed logistics process. Although this stage of data collection resembles a pilot study, the data collected was so extensive and of such a quality that the results were included as one of the multiple case studies.

Semi-structured interviews and observations. A round of semi-structured interviews was conducted with managers at the remaining four case study hospitals. The interviewed managers were responsible for the bed logistics process at each of the case study hospitals. In addition, the bed logistics process was observed at each hospital. Collected data was at this stage analyzed to identify a list of impact factors affecting the decision to improve healthcare logistics processes.

Structured interviews. A round of structured interviews was carried out at each of the five hospitals. The impact factors identified in the previous stage were presented to the managers responsible for the bed logistics process for validation. Thus, the respondents confirmed the importance of the identified decision criteria for a decision to improve the bed logistics process by assigning a value of 0-10. This stage of data gathering therefore served the purpose of validating and ranking the identified impact factors.

An overview of data gathered for case study A is found in Table 3.3. The table lists the interviews and observations carried out and the documents obtained from the case study hospitals.

Table 3.3. Overview of data collected for case study A

Organization	Data source	Type of data
Hospital 1	Logistics deputy manager	1 interview
	Head of Transp. unit and a project coord.	1 interview
	Transport unit project coordinator	2 interviews
	Head of transport	1 interview
	Logistics project coordinator	1 interview
	Head of technical maintenance	1 interview
	Head of technical maintenance and a repairman	1 interview
	Representative from supplier	1 interview
	Data responsible	1 interview
	Head of cleaning department	1 interview
	Hygiene nurse	1 interview
	Stages of transport	4 observation sessions
	Conveyor system	1 observation session
	Central bed cleaning	2 observation sessions
	Previous workshop data	2 documents
	Pick-up of dirty beds	4 reports
	Mattresses and pressure ulcers	3 reports
	Bed cleaning metrics	1 report
	Department overview	1 overview
	SOP for managing beds	1 SOP
	Hygiene principles and standards	1 document
Hospital 2	Head of bed cleaning	2 interviews
	Bed cleaning process	1 observation session
Hospital 3	Head of bed cleaning	2 interviews
	Bed cleaning process	1 observation session
Hospital 4	Head of bed cleaning	2 interviews
	Bed cleaning process	1 observation session
Hospital 5	Head of bed cleaning	2 interviews
	Bed cleaning process	1 observation session
	Improvement project documents	8 project files

3.8.9 Data collection case study B: Hospital cleaning in Denmark

For the Danish hospital cleaning case, twenty interviews were carried out at the primary case hospital, the cleaning process was observed on one occasion, and several documents were collected. Interviewees included managers and employees in the cleaning organization. In addition, clinical staff was interviewed to broaden the perspective to the customer of the cleaning service. Limited data was gathered from another hospital in the same hospital region to gain an understanding of how other hospitals in the region perform the same process. In addition, staff was interviewed from the IT department of the Danish hospital services to learn about the strategy and opinions of the IT department. Furthermore, staff from the central lean and strategy department of the hospital region was interviewed to learn about continuous improvement efforts in the hospital region and how it might relate to healthcare logistics processes.

The purpose of the case study was to validate the impact factors identified in case study A for a hospital cleaning process and for track and trace technologies. Table 3.4 provides an overview of data collected for case study B.

Table 3.4. Overview of data collected for case study B

Organization	Data source	Type of data
Primary case hospital	Head of hospital logistics	2 interviews
	Head of the Cleaning department	3 interviews
	2 supervisors in the Cleaning department	2 interviews
	Planning coordinator for cleaning	2 interviews
	OR logistical services coordinator	2 interviews
	2 head nurses	2 interviews
	Hygiene nurse	1 interview
	Cleaning process	1 observation session
	Examples of quality reports	3 reports
	Ex. of report of patients in isolation	1 report
	Example of map of ward	1 map
	Hygiene standards	1 document
	Overview of room categories	1 document
	Meeting minutes – management meeting	1 document
Other hospital	Manager of Cleaning department	1 interview
	Lean consultant	1 interview
Central Lean and Strategy unit for the hospital region	Lean consultant	1 interview
Central IT department for Danish healthcare	2 heads of IT architecture	2 interviews
	IT platform project manager	1 interview

3.8.10 DATA COLLECTION CASE STUDY C: PHARMACEUTICAL DISTRIBUTION IN DENMARK

Seven semi-structured and one structured interview were conducted for the pharmaceutical distribution process in Denmark. Observations of the pharmaceutical distribution process were carried out on four occasions. Interviews and observations took place at the primary case hospital and limited data was obtained from another hospital to provide perspectives from another setting. Furthermore, interview and observations were carried out at the regional warehouse supplying the hospitals in the region with pharmaceutical products. The interviewee also provided documents relating to the supply of pharmaceuticals to hospitals. Table 3.5 provides an overview of data collected for case study C.

Table 3.5. Overview of data collected for case study C

Organization	Data source	Type of data
Primary case hospital	Head of transport unit	1 interview
	Distribution of pharmaceuticals	1 observation session
	Deputy manager of logistics	2 interviews
	Supervisor in Transport unit	1 interview
Other hospital	Responsible for pharmaceutical transport	1 interview
	Head pharmaconomist	1 interview
	Pharmaceutical replenishment in wards	1 observation session
	Distribution of pharmaceuticals	1 observation session
Regional pharmaceutical warehouse	Head of logistics in regional warehouse	1 interview
	Inventory and picking process	1 observation session
	Volumes of pharmaceuticals	4 documents
	Organizational chart and responsibilities	1 document

3.8.11 DATA COLLECTION CASE STUDY D: BED LOGISTICS IN THE US

Seven semi-structured interviews and four observation sessions were carried out to learn about the bed logistics process at the US hospital. For the validation round, one structured interview was conducted with the program manager of Environmental Services and a survey was sent to the head of the Patient Transfer department and to the director of Patient Transportation. In addition, some documents were provided from the department of Environmental Services. Table 3.6 provides an overview of data collected from the case study.

Table 3.6. Overview of data collected for case study D

Organization	Data source	Type of data
US hospital	Head of the Patient Transfer department	1 interview + survey
	Director of Patient Logistics	1 interview
	Senior Director and program manager of Environmental Services	1 interview
	Department manager of Patient Transportation	1 interview
	Director of Patient Transportation	1 interview + survey
	Head of Service Express call center	1 interview
	Program manager of Environmental Services	Survey
	Head of Bed Management unit	1 interview
	Service Express call center operations	1 observation session
	Patient transport process	1 observation session
	Bed management call center	1 observation session
	Cleaning process	1 observation session
	Service level agreement	1 document
	Presentation of the Environmental Services organization and operations	2 presentations

3.8.12 DATA COLLECTION CASE STUDY E: PHARMACEUTICAL DISTRIBUTION IN THE US

Six semi-structured interviews and four observation sessions were carried out for the first round of data collection for the US pharmaceutical distribution process. For the validation round, a survey was sent to the continuous improvement manager for the pharmacy and the pharmacy assistant director. Table 3.7 provides an overview of data collected for case study E.

Table 3.7. Overview of data collected for case study E

Organization	Data source	Type of data
US hospital	Continuous improvement manager (pharmacy)	2 interviews + 1 survey
	Head of pharmacy informatics	1 interview
	Pharmacy assistant director	1 interview + survey
	Director of supply chain IT	1 interview
	Inpatient pharmacy operations manager	1 interview
	Outpatient and inpatient pharmacy	1 observation session
	Automated guided vehicles in operation	1 observation session
	Inpatient pharmacy operations	1 observation session
	Inpatient pharmacy receiving	1 observation session
	National patient safety goals	1 document
	Example of performance report	1 report

3.8.13 STAKEHOLDERS AND GOVERNANCE OF THE PHD PROJECT

During the course of the research project, a number of stakeholders had an interest in the outcome of the project. The main stakeholder of this project is the funding hospital. Thus, the managers granting the funding for this research project have an interest in the practical implications of the project and to some extent the scientific contribution. It was a distinct motivation of the logistics manager of the funding hospital to attain scientific evidence of how to improve the logistics processes of the hospital as this type of evidence would resonate with executive managers and clinical staff.

During the course of the PhD project, regular meetings were held with the manager and deputy manager of the logistics department of the funding hospital. During these meetings, processes were selected for investigation in the case studies through a joint discussion. Similar meetings were held to ensure progress and set the direction of the case studies. The ongoing discussions between researcher and managers ensured that the issues addressed in the research and the direction of the research was of continued relevance to the "real world", which is a prerequisite for good research (Karlsson, 2016). Contacts for each Danish case study were obtained through the manager and deputy manager of the logistics department. Most of the interviews and observations were carried out with staff from the logistics department, but other departments were also engaged. At the end of each project, handover meetings were held with the same group of stakeholders to ensure that knowledge, findings and recommendations from the case studies were shared with the managers.

The employees working with the investigated processes have an interest in the outcome of the projects as any changes to the process would affect their work. Thus, these employees would have an interest in the way their work is perceived and portrayed. It was made clear to the employees participating in the research project that the intent was not to report on how they perform as individuals but to suggest how to make their job easier and to hear their ideas for improvement.

The case studies conducted at the US hospital served a different purpose than those conducted in the Danish case study hospitals. The association with the US hospital was looser in terms of the extent of management commitment and lack of financial involvement. The mandate as a researcher in the US hospital was therefore different from the main case hospital. The connection with the US hospital happened through involvement with the Continuous Improvement department of the hospital. Connections with the appropriate managers overseeing the case study processes were therefore established through a liaison in the Continuous Improvement department. The appropriate managers would then provide access to employees and data from their organization. Due to the nature of the affiliation with the US hospital, access to data was more limited, yet managers and employees were most helpful and obliging in acquiescing to any requests. Managers did not expect any outcome from the project and employees knew that findings from interviews and observations would not be reported back to management. Employees would therefore not have motives to portray their work in a certain way.

3.9 Analysis

This section describes how qualitative and quantitative data were analyzed for this study.

3.9.1 Analyzing qualitative data

This sub-section describes the analytic strategy, analytic techniques and coding of qualitative data.

Analytic strategy. The analytic strategy adopted in this study lies somewhere in between "relying on theoretical propositions" and "working data from the 'ground up'" (Yin, 2014). The constructs in Figure 3.3 together with the framework developed by Jørgensen (2013) provide a type of a priori codes and is illustrated in Figure 3.6. The specific impact factors, were partly identified by a "ground up" approach resembling grounded theory (Corbin and Strauss, 2015), but was also compared to the underlying factors of the framework developed by Jørgensen (2013).

Analytic techniques. Yin identifies five techniques for analyzing data: 1) pattern matching, 2) explanation building, 3) time-series analysis, 4) logic models and 5) cross-case synthesis (Yin, 2014). This study utilizes the pattern matching technique by applying a theoretically based pattern to analyze data. This pattern can be viewed as a type of preliminary framework to analyze the data. The pattern is illustrated in Figure 3.6. Furthermore, Eisenhardt suggests two types of analysis: 1) analyzing within-case data and 2) searching for cross-case patterns (Eisenhardt, 1989). Both within-case data and cross-case patterns are identified in this study and the analysis therefore shares some resemblance to the cross-case synthesis.

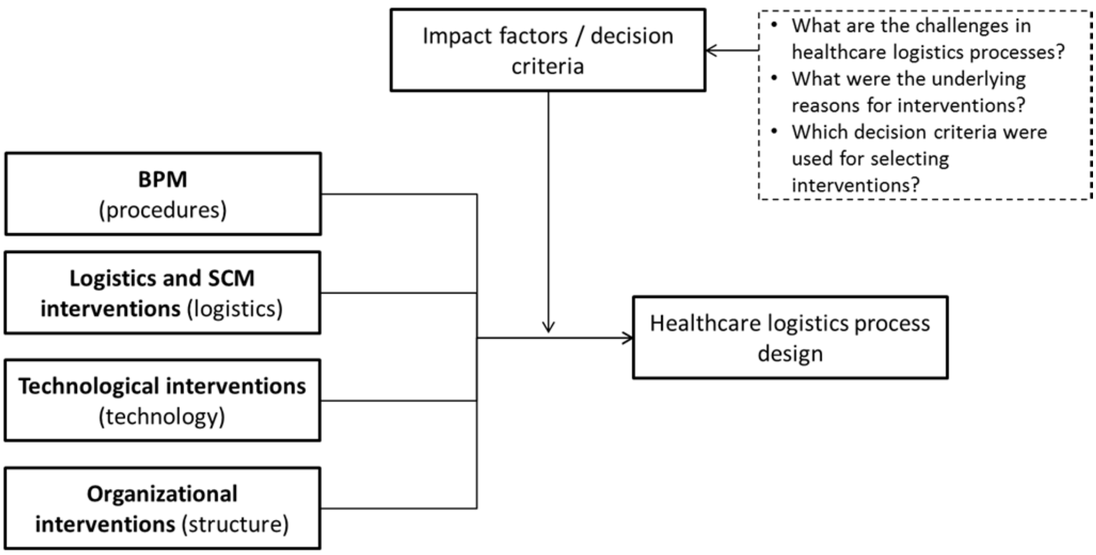

Figure 3.6. Theoretically based pattern for analyzing case study evidence using pattern matching

The concepts BPM, logistics and SCM interventions, technological interventions, and organizational interventions indicated in Figure 3.6 were identified in the literature review as types of interventions for improving healthcare logistics processes. The parentheses indicate the constructs that will be used in the framework developed in this study.

Coding data. According to Miles et al., codes are “labels that assign symbolic meaning to the descriptive or inferential information compiled during a study”. Furthermore, coding reduces data into categories and is a type of analysis that enables interpretation to understand the meaning of data (Miles et al., 2014). Codes are assigned to portions of data to identify reoccurring patterns. In this study, data was coded and recoded, i.e. two coding cycles (Miles et al., 2014). In the first coding cycle, concepts were identified. The pattern in Figure 3.6 provided a priori codes and is consistent with the framework developed by Jørgensen (2013). The framework developed by Jørgensen consists of the four constructs logistics, technologies, structure, and procedure. In addition, the framework developed by Jørgensen consists of underlying factors relating to each construct (Jørgensen, 2013). These underlying factors were compared to the codes emerging from data, revealing existing and new codes. In the second cycle of coding, codes were re-grouped and categorized. This iterative coding process ensures consistency across data and cases. The codes represent the impact factors identified in this study and form the empirical basis for the developed framework.

Interview and observation data was coded to reflect 1) challenges, 2) reasons for implementing interventions, and 3) applied decision criteria for interventions. The codes thereby translate into factors impacting the design of healthcare logistics processes, which in turn can be used as decision criteria for improving healthcare logistics processes according to the needs and preferences of hospitals. The respondents were asked about the applied decision criteria and reasons for implementing changes as these aspects directly relate to factors impacting the design of healthcare logistics processes. Challenges were included to identify impact factors as overcoming what is considered a challenge would help improve a process. The coding process is illustrated in Figure 3.7.

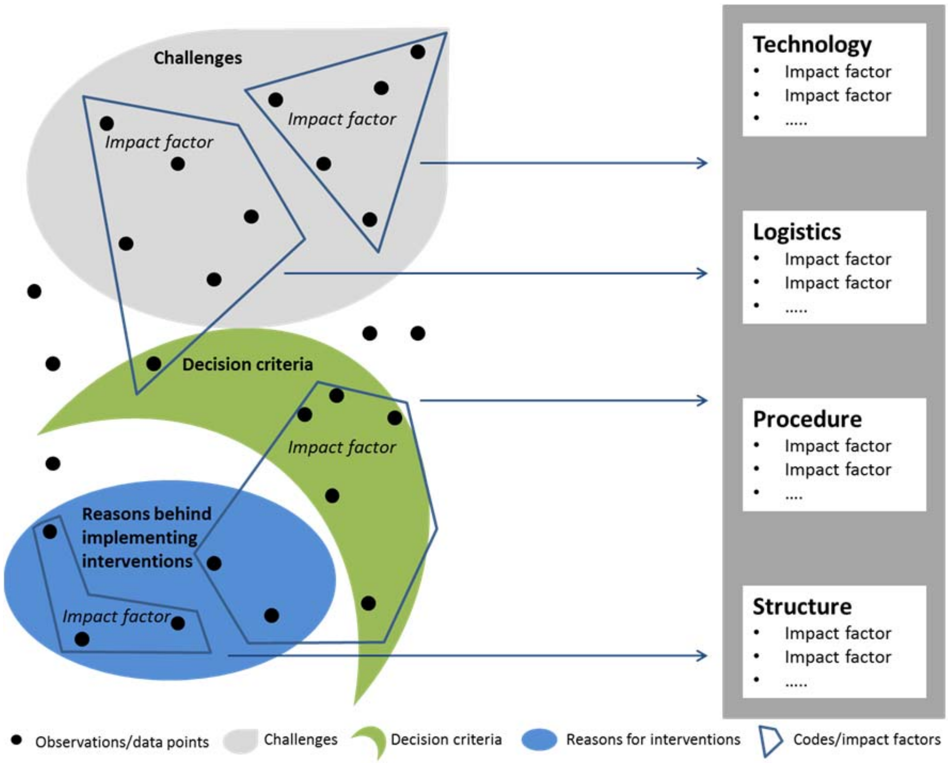

Figure 3.7. Coding process and link to impact factors

3.9.2 Quantitative data analysis

For data gathered from the Danish and US bed logistics case studies and the US pharmaceutical distribution case study, impact factors were ranked as decision criteria on a 0-10 scale according to the importance for improving healthcare logistics processes. Based on the assigned values, decision criteria could be ranked according to process and country setting. Furthermore, differences in perceived importance amongst respondents within a case and across cases could be identified based on the calculated averages and standard deviations. In the Danish hospital cleaning case, the ANP method was applied, first to prioritize alternative solutions and second to prioritize the importance of each decision criterion.

3.10 Quality of research

Each of the quality aspects of rigorous case study research considered in this study is discussed in the following. The quality aspects include construct validity, internal validity, ecological validity, external validity, i.e. generalizability, and reliability.

3.10.1 Construct validity

Construct validity is mainly related to the data gathering phase and refers to the extent to which a study investigates what it claims to investigate (Denzin and

Lincoln, 1994). Construct validity was ensured through triangulation by gathering and analyzing data from different sources and by adopting different strategies for data gathering (Ellram, 1996; Voss et al., 2016). Different sources of information were accessed, namely managers and employees across different hospitals, and different organizational units within a hospital. The main strategies adopted for collecting data were interviews and observations. Furthermore, validation was ensured through respondent validation (Bryman, 2012) where findings were reviewed by key informants (Ellram, 1996; Yin, 2014) and finally presented and discussed with management at the primary case hospital. As a final point on construct validity, ensuring coherence between research questions and conclusions by providing an understandable chain of evidence is vital for the internal validity of the study (Ellram, 1996; Yin, 2014). This chain is evident in the links between each part of this thesis: the Introduction motivating the study and from which the research questions emerged; the Literature Review enfolding what is already known about the research topic to identify a research gap and justify the current study; the Methodology justifying and detailing how the research questions are answered; the Results presenting the findings of the study and linking data to findings; answering the research questions in the Discussion; leading to the Development of the Final Framework; and lastly the Conclusions to conclude on the findings of the entire thesis.

3.10.2 Internal validity

Internal validity is only appropriate for explanatory or causal studies and is mainly relevant to the data analysis phase (Yin, 2014). Internal validity refers to the causal relationship between variables and results. Similar findings across studies, i.e. pattern matching increases internal validity (Denzin and Lincoln, 1994; Eisenhardt, 1989; Yin, 2014). In this study, the findings across cases are compared and similar patterns identified. Addressing rival explanations is vital in improving the internal validity of the study (Yin, 2014). In abductive reasoning, the most likely explanation is pursued which can account for observations. Thus, possible rival explanations are sought out and discarded as other explanations become increasingly more compelling (Miles et al., 2014). The developed framework has therefore undergone several iterations until the final iteration of the framework was settled.

3.10.3 Ecological validity

When conducting direct observations, the presence of the researcher may affect the behavior of the people observed. Ecological validity is concerned with whether research findings are applicable to people's natural social settings (Bryman, 2012). The observed employees were aware that they were being observed and were also familiar with the purpose of the observation. The purpose of the observations was to learn about the process steps and the challenges in the processes. Thus, it was not the individual employee performance that was being investigated, but rather the process steps. Furthermore, it was in the employees' own interest to identify the challenges in the process. However, the employees' fear of being replaced could affect their behavior to give an impression of higher efficiency than under normal circumstances. The study can be considered as being conducted in a relatively realistic setting and findings are therefore expected to be generalizable to a real-life setting.

3.10.4 EXTERNAL VALIDITY

External validity establishes within which domain findings can be generalized. Conducting case study research faces some limitations such as a generalization issue. Case studies aim for analytic generalization instead of statistical generalization. Thus, case studies do not aim to generalize universally but to find out under which conditions certain outcomes can be predicted (Yin, 2014).

The generalization of case studies occurs at a conceptual level and not merely at the level of the specific case. Analytic generalization of a case study is based on either 1) advancement of theoretical concepts, e.g. through corroboration, modification or rejection, or 2) new concepts emerging from the case study (Yin, 2014). In this study, analytic generalization will be based on both the advancement of existing concepts and the identification of emerging concepts.

To improve external validity, multiple case studies were conducted. The identification of patterns across cases, e.g. the identification of impact factors in the case studies, enhances external validity (Voss et al., 2016). Furthermore, the use of a case study protocol improves the external validity of this study (Yin, 2014).

The domain of a theory limits the generalizability of the theory (Wacker, 1998). The domain of this study was outlined in a previous section in this chapter. Generalizability of this research is limited to a healthcare logistics context for Denmark and the US and needs to be tested for other countries and settings. Furthermore, the investigated logistics processes are limited to the bed logistics process and pharmaceutical distribution process for Denmark and the US and the hospital cleaning process for Denmark. The matrix in Figure 3.8 illustrates how each case study contributes to generalizability in terms of method, country setting, process type, technology types/process design, and benchmarking/performance measurement. Thus, each case study generalizes findings according to the investigated process and the country setting. Furthermore, case C generalizes in terms of applying the ANP method to the developed framework. In addition, each case generalizes the findings in terms of applying the developed framework to the assessment of technologies or process improvement approaches. Finally, all case studies in one way or the other contribute to benchmarking or performance measurement. The contribution to performance measurement is both in terms of defining performance metrics and capturing data. Figure 3.8 therefore also reflects the replication logic used for the case studies, i.e. to logic used for selecting two or more case studies (Yin, 2014).

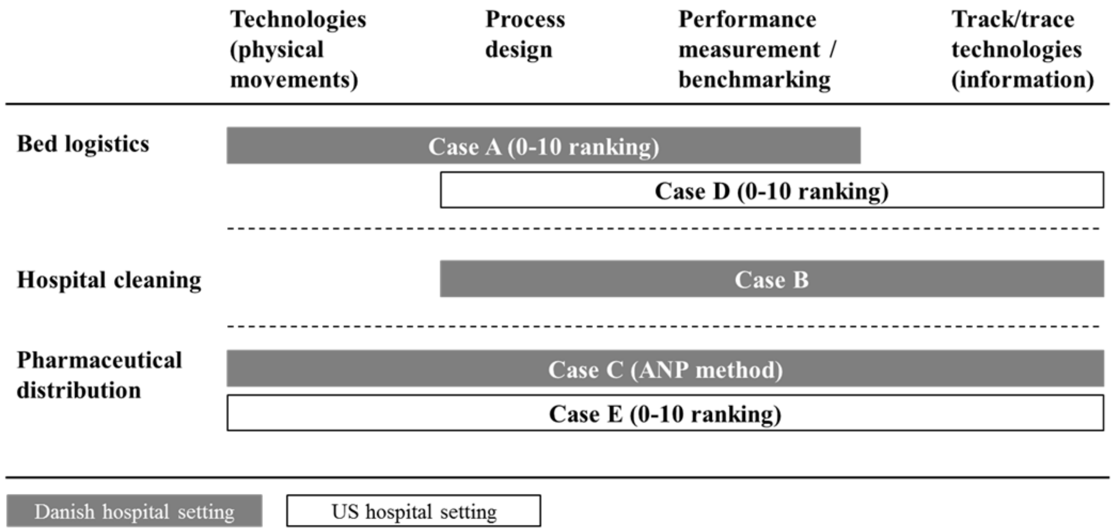

Figure 3.8. Generalizability of case studies

Findings from case studies may apply to other cases that do not strictly match the circumstances of the investigated case (Yin, 2014). Matching findings across the conducted case studies makes it possible to conjecture that the findings are likely to apply to other healthcare logistics processes than those specifically investigated in this study and furthermore for other hospitals in developed countries.

3.10.5 RELIABILITY

Reliability refers to the extent to which the same results and conclusions would be reached if the study were repeated. Reliability was ensured through colleague review and triangulation (Eisenhardt, 1989; Miles et al., 2014). The use of a case study protocol enhances the reliability of the study (Yin, 2014), which is further enhanced by providing transparency of the research process (McCutcheon and

Meredith, 1993; Voss et al., 2016). A detailed account of the research process and details of the research protocol have therefore been provided. Furthermore, the link between data and findings through coding is detailed in the Results.

3.11 THE NATURE OF SCIENTIFIC CONTRIBUTIONS AND PRACTICAL IMPLICATIONS

A theoretical contribution should be both of interest to practice and generalizable (Boer et al., 2015). Thus, the research questions investigated in this study are rooted in both a theoretical and practical need as argued in the Introduction. Furthermore, the maturity of a research field determines the possible contributions to the field. Edmondson and McManus distinguish between three levels of theory maturity. First, nascent theory proposes tentative answers to "how" and "why" questions, suggesting new relationships between phenomena in a context of little or no existing theory. Second, intermediate theories are based on extant literature and often rely on different streams of literature. Third, mature theories consist of well-developed constructs and models, which have been developed based on extensive research conducted in different settings (Edmondson and McManus, 2007).

As a realist stance is taken in this study, a contribution "consists of a better or more inclusive explanation of observed, or observable, phenomena" (Boer et al., 2015). Boer et al. (2015) further argue that there are two fundamental ways of contributing to theory: exploratory studies or confirmatory work. Exploratory studies observe and identify phenomena that cannot be explained well enough by existing theory. Confirmatory work puts propositions to the empirical test in a given context. Furthermore, contributions can be less formal in nature, e.g. by pointing out flaws in existing theory when applied to a different context or by identifying areas where extant literature is insufficient. In this study, impact factors are identified to explain the decision to implement interventions for improving healthcare logistics processes. Furthermore, the findings are validated by applying a quantitative approach to the initial exploratory qualitative approach. The so-called "less formal" contributions of this study are the findings of the conducted literature review. The literature review maps extant literature on the topic of healthcare logistics and offers an agenda for future research. Finally, a decision framework is developed based on the literature review and the empirical research performed in this study.

In terms of practical implications, this study offers suggestions for interventions to improve healthcare logistics processes and a framework to help decide which interventions to implement. The theoretical contributions and practical implications of this study are explicated in the Conclusion.

3.12 Chapter summary

This chapter details the methodological approach of this study. A critical realist philosophical stance is taken and the implications for the research design have been described. The meta-RQ investigated in this study was broken down to three RQs and eight SQs and linked to the research questions investigated in each paper. Case study as research design and mixed methods research as research strategy were justified and described and the procedure for collecting data for each case study has been explained in detail. The process of analyzing the collected data through coding for qualitative data and the prioritization of impact factors as decision indicators has been outlined. The measures for ensuring quality of research have been described in terms of validity and reliability. Finally, the nature of scientific contributions and practical implications of this study are characterized.

4 RESULTS

This chapter presents the results of the study based on the data collected from the case studies. The chapter includes three blocks of comparisons: 1) a comparison of case characteristics, 2) a comparison of interventions and 3) a comparison of impact factors. First, the case studies are introduced and case characteristics compared. The case characteristics include process descriptions and challenges in healthcare logistics. Interventions for improving healthcare logistics processes are then reported. Based on the challenges and interventions, impact factors for improving healthcare logistics processes are identified. The identified impact factors are then consolidated and compared across cases. Suggestions for applying the impact factors as decision criteria for improving healthcare logistics processes are provided and Part II of the final framework is developed. Finally, a chapter summary is provided.

4.1 COMPARING CASE CHARACTERISTICS

The Danish and US case study hospitals are briefly described in the following. Table 4.1 provides an overview of the case study hospitals. The primary case hospital, which is the funding hospital, is denoted “DK hospital 1”. The table indicates how many bed spaces each hospital can occupy, the number of actual beds, the number of beds that are cleaned per day, and whether the hospital offers a 24 hour emergency department (ED). Four of the hospitals offer a 24 hour emergency department and two of the hospitals offer emergency services for limited hours of the day.

Table 4.1. Overview of case study hospitals

Hospital	# beds occupied	# actual beds	# beds cleaned per day	24 hour ED
DK hospital 1	700	1,200	235	Yes
DK hospital 2	600	800	250	Yes
DK hospital 3	500	1,200	175	Yes
DK hospital 4	300	560	110	No
DK hospital 5	250	500	120	No
US hospital	1,250	1,250	200	Yes

All the Danish case hospitals are public hospitals located within the same hospital region. Each hospital offers a variety of patient care services and treatments, but may specialize in certain areas, e.g. eye surgery, cancer treatment etc.

The US case hospital is considered one of the best hospitals in the US. The hospital is owned by a non-profit organization with branches located across the US and abroad. This study focuses on the main campus of the hospital, which covers all medical specialties.

Table 4.2 provides an overview of how the case hospitals contribute to each case study. For case B, Hospital 1 was the main case hospital, but limited additional data was collected from another major hospital in the capital region of Denmark, which is not included in Table 4.2 as it is not a case hospital. For case C, Hospital 1 was the main case hospital, but additional data was collected to a limited extent from Hospital 4.

Table 4.2. Overview of hospitals contributing to each case study

Hospital	**DK bed logistics**	**DK hospital cleaning**	**DK pharmaceutical distr.**	**US bed logistics**	**US pharmaceutical distr.**
DK hospital 1	X	X	X		
DK hospital 2	X				
DK hospital 3	X				
DK hospital 4	X		(X)		
DK hospital 5	X				
US hospital				X	X

A brief description of each case study is provided in the following. The descriptions include a description of the process and the people involved in the process. Challenges experienced for the processes, implemented technologies and other improvement initiatives are discussed in separate sections in this chapter.

4.1.1 Case A: The bed logistics process in Danish hospitals

The bed logistics flow in the Danish case study hospitals is illustrated in Figure 4.1. The clinical departments are responsible for assigning patients to beds and discharging the patients. The cleaning department cleans the rooms, including beds, during the patient stay and upon discharge. The transportation department is responsible for transporting the patient to treatments during the patient stay, for transporting clean beds to patients, and for transporting used beds to the central cleaning area for the bed cleaning team. Some of the hospitals use special washing machines to wash the beds while others clean the beds manually. According to the managers of bed logistics in the case hospitals, washing beds with washing machines provides the best output in terms of cleanliness.

The information flow within the process is limited; apart from admission and discharge data, limited information exists regarding the bed transportation and bed cleaning processes.

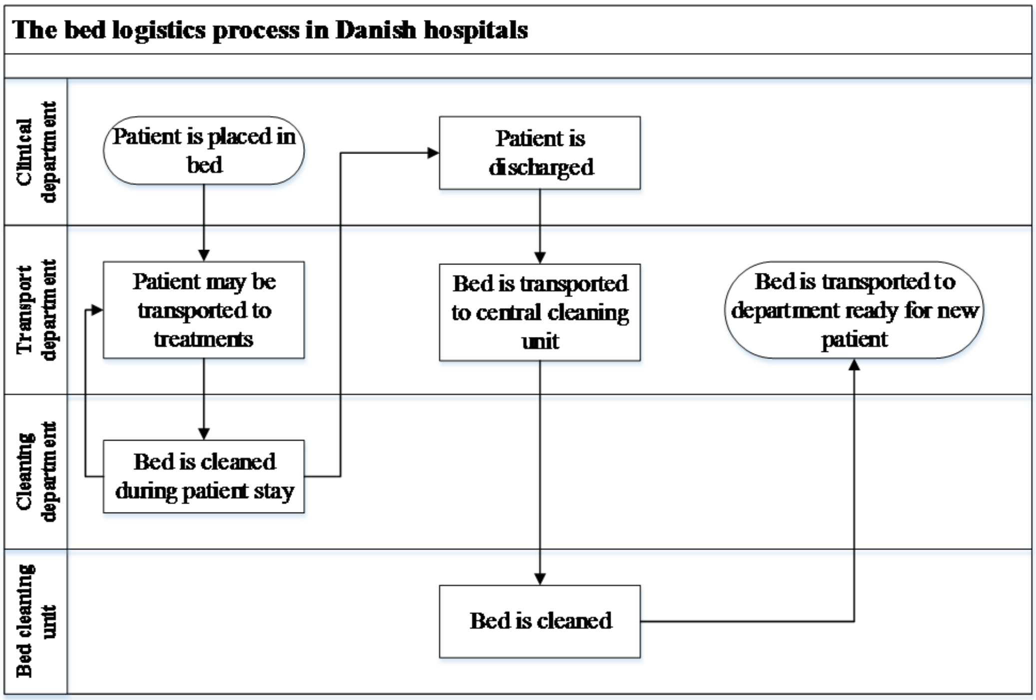

Figure 4.1. Bed logistics process at Danish hospitals

4.1.2 CASE B: THE HOSPITAL CLEANING PROCESS IN A DANISH HOSPITAL

The hospital cleaning process consists of three overall steps as illustrated in Figure 4.2.

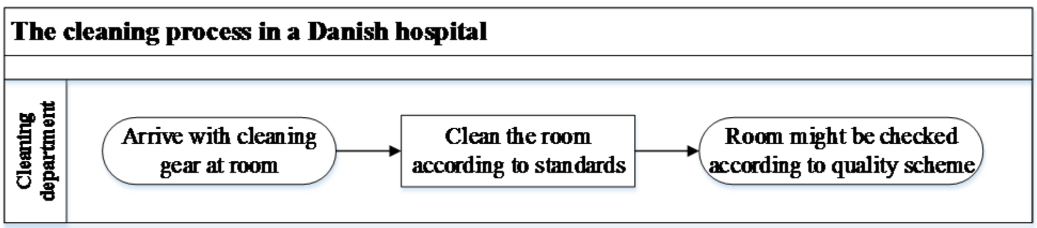

Figure 4.2. Hospital cleaning process at Danish hospital

The first step of the cleaning process is the arrival of cleaning staff and cleaning gear at the place to be cleaned. The room is then cleaned by an individual from the cleaning department. The room should be cleaned according to cleaning standards by following a set of guidelines. It is expected that a certain amount of time is spent on cleaning a room to ensure that cleaning is performed to a satisfactory standard. For quality assurance purposes, a random sample of rooms is checked daily according to a quality scheme. The quality of cleaning is important for the hospital as a step to contain any infections and to prevent infections from spreading throughout the hospital. However, it is time consuming and difficult to check the quality of a performed cleaning task, thus only a sample of rooms is checked. It is difficult to ascertain whether a room has been cleaned satisfactory because a room may look clean without actually being clean. Taking a biological sample for testing is an even more elaborate and time consuming task and is conducted to a lesser extent. The only measures documented for the cleaning process are therefore time stamps for cleaning certain types of rooms and the performed quality checks of a sample of rooms. Over time, adherence to quality is measured per employee and per unit.

4.1.3 Case C: The pharmaceutical distribution process in a Danish hospital

For the Danish hospital, pharmaceutical products are ordered four times a week by pharmaconomists and pharmacists employed at the regional warehouse. Orders are made based on a reorder point of five days' worth of stock. Pharmaceutical products are delivered to the hospital docking area from the regional warehouse. The items are then transported to an area where boxes of pharmaceutical products are rearranged according to the receiving department. Subsequently, items are delivered to the clinical departments where they are stored. The pharmaceutical distribution process is illustrated in Figure 4.3.

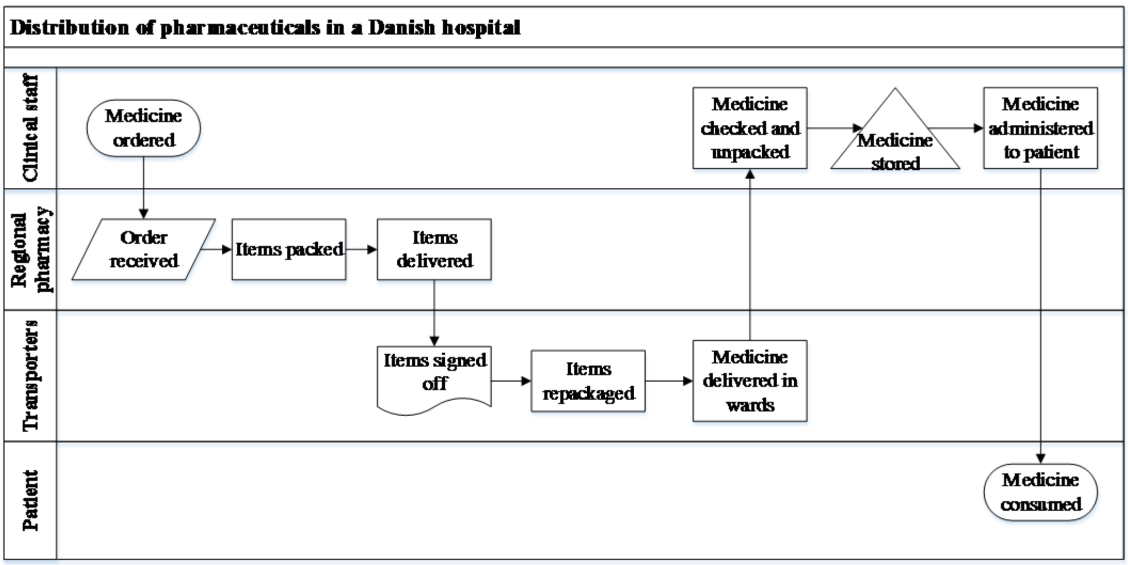

Figure 4.3. Pharmaceutical distribution process in a Danish hospital

The distribution of pharmaceutical products is scarcely documented and it is impossible to track the progress of the delivery of items. Upon receiving the products from the regional warehouse, the products are signed off manually by hospital staff to document that the items have been received. When the items are delivered to the receiving clinical department, the department does not sign off for the delivery. Furthermore, the received items are not matched with the orders until items are received, unpacked and stored in the departments. When pharmaceuticals are administered to the patients, the use of barcodes ensures that the right medicine is administered to the right patient. The main concern in the case study is the forward flow of products, although a reverse flow also exists.

4.1.4 Case D: The bed logistics process in a US hospital

In contrast to the Danish bed cleaning process, the US bed cleaning process is decentralized as all beds are cleaned in the wards. The bed logistics process at the US hospital is illustrated in Figure 4.4. The information level in the US bed logistics process is higher than for the Danish process; i.e. in addition to admission and discharge data, certain time stamps are registered for patient transport and cleaning.

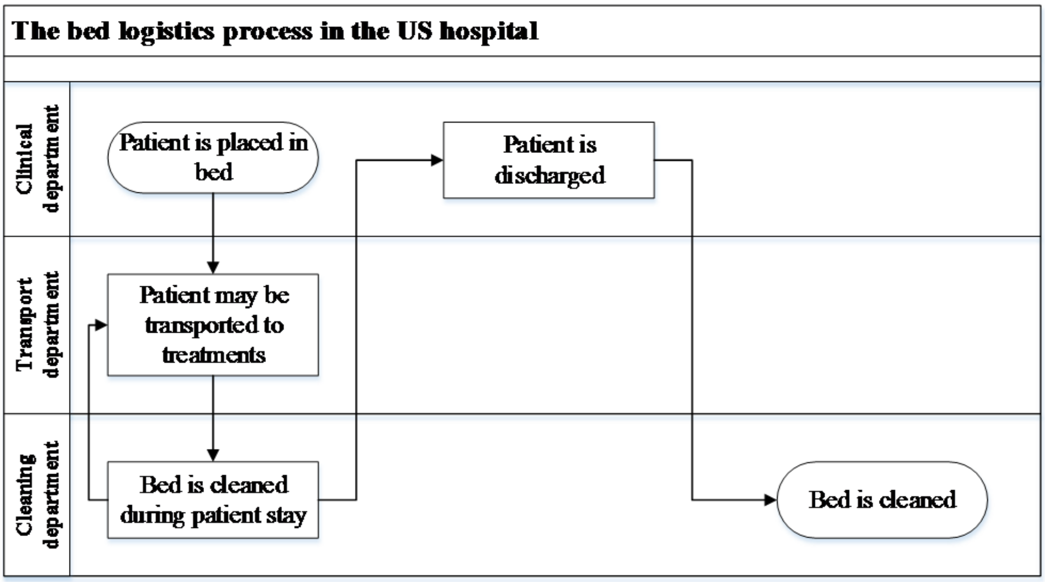

Figure 4.4. The bed logistics process in the US hospital

A range of organizational units are involved in the bed logistics process; Bed Management is responsible for assigning beds to patients, Cleaning Services is responsible for cleaning the rooms and beds, and Transportation is responsible for transporting patients to the assigned rooms and to/from treatments. Finally, the clinical departments are responsible for admitting and discharging patients.

4.1.5 Case E: The pharmaceutical distribution process in a US hospital

The pharmaceutical distribution process investigated in this case relates to the inpatient pharmacy of the US hospital. The hospital also includes a number of outpatient pharmacies, i.e. drugstores. Figure 4.5 depicts the forward flow of drugs for the inpatient pharmacy, although a reverse flow exists for drugs which have not been used. The drug flow is enabled through various information systems that also provide process information. Between each handover in the process, the drugs are scanned using barcodes in order to 1) enable tracking of the items throughout the process and 2) check that the correct items are handed over. Thus, at any point in time, the location of any pharmaceutical item is known from the point of delivery in the pharmacy until the product is administered to the patient. Most items are held in a central inventory and stored in a semi-automated picking carousel, where items are checked and registered using barcodes. In each clinical department a medication dispensing station has been installed, and all drugs entering and exiting the dispensing stations are checked and registered. The rigorous track and trace enabled by barcoding is in place to ensure adherence to the strict rules of the US Food and Drug Administration (FDA).

The pharmaceutical distribution process has moved towards de-centralization, although part of the process is still centralized. The dispensing stations in each department are refilled daily from the central inventory at a pre-scheduled time. Patient specific prescription drugs are sent to the departments separately throughout the day. EDI is used to automatically reorder high volume drugs from vendors when central inventory levels reach the reorder point of five to seven days' worth of stock.

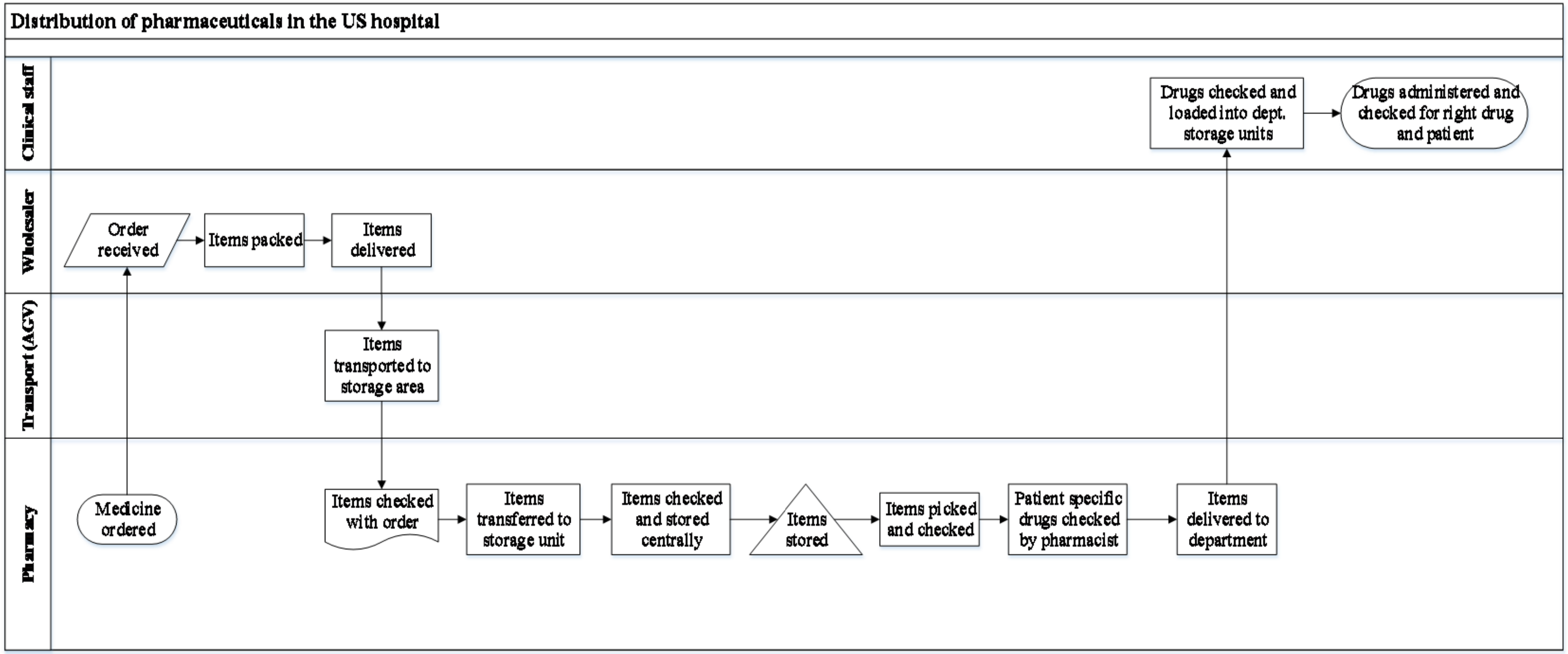

Figure 4.5. The pharmaceutical distribution process in the US hospital

4.1.6 COMPARING HEALTHCARE LOGISTICS PROCESSES

The investigated processes differ in terms of the number of process steps, organizational involvement, level of technology adoption, and the nature of the flow. Figure 4.6 visualizes how the processes compare in terms of process steps and organizational involvement. Enhanced maps are found in Figure 4.1 to 4.5.

Centralization vs. decentralization. The bed logistics process, case A and D, consists of several different process steps, each of which is performed by different departments and requiring different skill sets. The US process is decentralized and the Danish process is centralized. By comparison, the hospital cleaning process, case B, consists of few process steps and involves one staff group. This cleaning process is decentralized, similar to cleaning in the US bed logistics process. The pharmaceutical distribution process, case C and E, comprises several process steps, although most process steps are carried out by one staff group. Both cases have decentralized inventories. In addition, the US hospital holds a central inventory, which supplies the decentralized inventories.

Automation. The investigated processes are mainly performed manually. The US pharmaceutical distribution process is partly automated and utilizes barcodes to a large extent. By comparison, the Danish hospitals utilize barcodes to a limited extent. Furthermore, most of the inventory is stored either in central semi-automated picking carousel or in the wards in automated dispensing machines in the US hospital. The pharmaceutical distribution process is subject to strict legislation, and automation supports better control of the process. In addition, automation in the US pharmaceutical distribution process provides data, which enables performance measurement, data analytics and improvement of processes.

Nature of flows. The bed logistics process consists of a closed-loop flow whereas the pharmaceutical distribution process is a linear open system flow, where pharmaceutical products enter and exit the hospital system. For the hospital cleaning flow, staff and equipment are redistributed daily, i.e. closed-loop, and only cleaning products enter and leave the system. Furthermore, the subjects of the flows differ in terms of size and variety. Pharmaceutical products appear in several different types and sizes, but are mostly delivered in relatively small or medium-sized boxes, whereas beds are large and almost identical in size and shape. In the hospital cleaning case, cleaning staff and equipment are the subjects of distribution. Each investigated process flow is somehow triggered by the patient flow. For the bed logistics process, the bed is used as a vehicle for transport.

For pharmaceutical distribution, pharmaceutical products are part of the patient treatment and encounter the patient at the point of consumption. For the hospital cleaning process, the room and bed is cleaned during the daily cleaning routines and both the bed and the room are cleaned upon discharge.

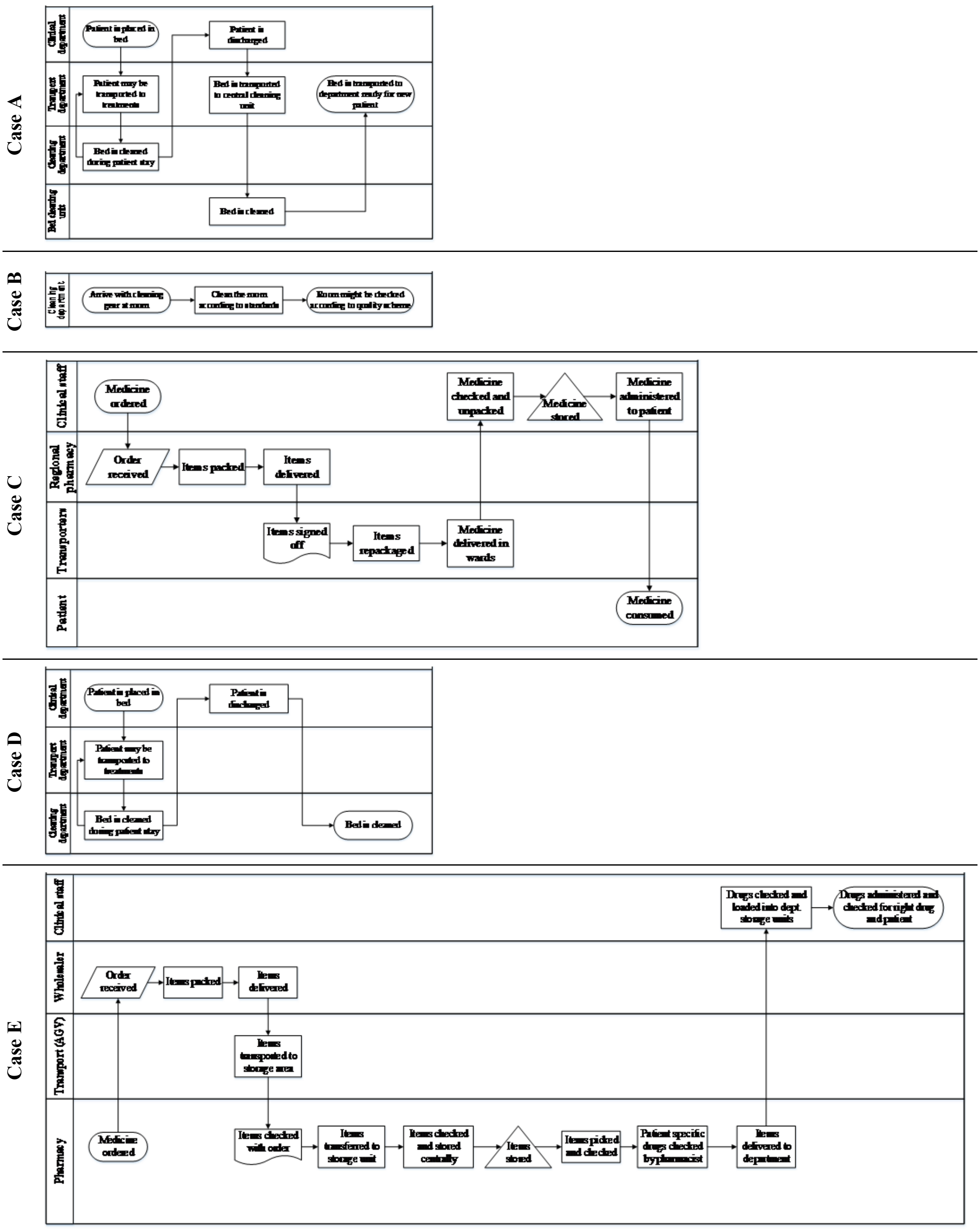

Figure 4.6. Visualization of process comparison

4.1.7 Comparing challenges in healthcare logistics

Challenges identified in the case studies are presented in the following. First, challenges identified for the bed logistics process and hospital cleaning process are presented. These two processes are treated together because the hospital cleaning process was to some extent embedded in both the Danish and US bed logistics cases, although a separate case was also conducted in Denmark. Second, challenges identified in the pharmaceutical distribution cases are described.

Challenges in bed logistics and hospital cleaning

The challenges of the bed logistics process and hospital cleaning process are presented in the following.

Variance. One of the main challenges of cleaning is the aim to drive out all variance in the process. I.e. for both the Danish and US hospital, it was a challenge to achieve the same clean result every time. Moreover, it is difficult to check whether a job has been performed adequately because a room can look clean without actually being clean. Furthermore, testing for biological matter is a difficult and time consuming process. One of the ways to limit variance is through proper training and SOPs.

Quality. One challenge experienced by clinical departments is the difference experienced in the quality of cleaning by temporary staff, which poses a particular issue during weekends and holiday season. This quality issue is related to the competencies of the employees.

Adherence. Ensuring that employees adhere to SOPs is particularly an issue for cleaning tasks. It is imperative that employees spend enough time cleaning each room for quality assurance reasons.

Challenging work conditions. Most of the logistics activities carried out within hospitals involve demanding physical work and repetitive tasks. Furthermore, resources are often hard pressed for time. Moreover, high absenteeism rates and employee turnover increase the pressure on existing resources.

Employee retention. Strenuous and repetitive work is one of the reasons for high turnovers for logistics staff in both Denmark and the US. For the Danish hospitals, it is an issue that the hospitals invest in training the employees who then move to a private company where the salary is higher. For the US hospital, however, some employees move to other jobs and use the entry job to move to a better position within the hospital. Managers in the US case study perceive this progression as a good thing for employees rather than a loss.

Employee absenteeism. The logistics departments often experience high absenteeism rates. This is partly due to the strenuous tasks involved for logistics activities. Furthermore, low levels of motivation may increase employee absenteeism.

Physical constraints. Old hospitals are often not designed with logistics in mind. E.g. the pace of the elevator to the central bed cleaning area in the primary case hospital together with the placement of the bed cleaning area impede the efficiency of the process.

Motivation. Logistics and cleaning staff perform repetitive tasks which are physically strenuous. In addition, these employees are often not viewed by other employee groups as equally important. E.g. as one physician in a Danish hospital noted:

> Transporters are perhaps more often blamed for things than they should be - even more so than for other staff groups.

Motivating employees is difficult because of the strenuous nature of the tasks and the lack of appreciation for the employees' work, which occurs in some hospitals. However, "how do you motivate someone that isn't really motivated?" as a manager in bed logistics pointed out. There is a lack of incentives to perform tasks well and to perform them according to the prescribed guidelines, e.g. process steps and equipment. Thus, employee turnover and absenteeism is high for most employees working in these types of jobs.

Impact on related processes. One of the goals for the hospital cleaning process is to ensure that the rooms are cleaned sufficiently to help avoid infections from spreading. Thus, the impact on related processes, in this case the patient care, is of high importance to the cleaning process.

Lack of data and performance measurement. Lack of data availability makes performance measurement difficult for the cleaning process in particular. For both the Danish and US hospitals, it is possible to track the progress of bed transports. In the US hospital, patient transport and the cleaning of discharge rooms are tracked through a teletracking system where the employee logs certain time stamps using a land line telephone. In the Danish hospitals, a mobile phone is used for tracking progress in patient transport and for tracking performance. For the cleaning process, it is difficult to measure performance because employees act on their own accord. Moreover, it is difficult to measure cleanliness and the time spent on cleaning, making performance measurement challenging for the cleaning process. In addition, the lack of performance measures has led to productivity issues for the bed logistics process. However, for both the Danish and US hospitals, a random sample of rooms are checked according to a quality control scheme, which is then measured per department and per employee over time.

Communication and information management. The cleaning department in the Danish hospital faces a significant communication challenge. First, it is challenging to convince others that a room has actually been cleaned. This challenge exists partly because it is difficult to see whether a room has been cleaned or not, and partly because the room may have been cleaned without anyone seeing it. Furthermore, only the cleaning of certain rooms is documented. Second, it is challenging to convince others that the room has been cleaned satisfactory. Third, the expected level of cleaning is higher than the required level of cleaning. Fourth, personnel often perform more tasks than agreed upon. Creating transparency around what is agreed and what is done is therefore a challenge.

Manual processes. For the most part, the investigated processes are manual. Moreover, for the Danish processes, data is mainly registered manually.

Excessive use of natural resources. Water is used for bed washing machines and for washing beds in general in Danish hospitals. Old washing machines in particular may use excessive amounts of water and the manual process makes it difficult to control the amount of water used.

Delays. For the US hospital, delays may occur in terms of supplying a clean bed for a new patient. However, this is more of an occupancy issue than bed logistics issue, although it does increase the pressure on cleaning staff for efficient and effective turnovers. Furthermore, patients are often transported to treatments in a bed. Delays may occur for both Danish and US hospitals due to delays in getting the patient ready for transport or due to delays in providing a transporter.

Balancing priorities. Especially for patient transports, balancing priority and non-priority calls can be a challenging task. Too many high priority tasks may result in the lower priority tasks continuously being queued and never being carried out.

Problematic handovers. Handover of a task from one employee or organizational unit to another increases the risk of mistakes (Hammer and Champy, 1993). Moreover, correct handovers requires that all parties involved in the handovers are educated accordingly. For the Danish bed logistics process in particular, it is an issue that different staff groups do not hand over beds to the next process step according to the guidelines.

Inefficient processes. The bed logistics process contains a number of inefficiencies, i.e. processes which could be avoided; waiting time, transport, lack of management oversight and inefficient use of resources are causes of low productivity.

Collaborating with and educating other staff groups. The tasks of logistics departments span across the hospital and employees must learn to collaborate with other staff groups. The handover of a task to a logistics employee affects how the logistics task is handled. One issue is that used beds are not left in the appropriate condition by the clinical departments for pick-up by transporters. For one of the Danish hospitals, this may disrupt the transport of beds via monorail and consequently the following cleaning process.

Locating people and items. For the cleaning process it is an issue to locate personnel and for the bed logistics process it is a challenge to locate beds.

Systems integration. For the US bed logistics process, particularly for the bed assignment unit, it is a challenge to work in several different systems that do not integrate.

The link between challenges and impact factors identified in the bed logistics and hospital cleaning case studies in both Denmark and the US is shown in Table 4.3. The impact factors only identified for the US bed logistics case study are listed in Table 4.4 and linked to supporting data. The tables thereby reflect the codes used for analyzing the qualitative data of this study.

Table 4.3. Challenges and impact factors identified for DK and US bed logistics/cleaning cases

Impact factors	Challenges
Consistency	• Driving out all *variance* in the hospital cleaning process • *Adherence* - lack of SOPs for the Danish bed logistics process
Risk of mistakes	• *Adherence* - lack of process knowledge • *Motivation* - lack of incentive to perform process correctly • Wrongful *handovers* between staff groups
Output quality	• *Adherence* - difficulties living up to cleaning requirements • Lack of *quality* measures • Differences in *quality* depending on permanent and temporary staff
Competence match	• Limiting process *variance* through training • Wrongful *handovers* between departments – beds are not handed over correctly • Ensuring *adherence* to SOPs
Competence shifts	• Wrongful *handovers* between departments – beds are not handed over correctly • *Collaborating with and educating other staff groups* for correct *handovers*
Unnecessary processes	• *Inefficient processes* cause low productivity; unnecessary processes should be eliminated.
Employee engagement	• Lack of incentives and *motivation* to perform tasks and to use technologies • Ensuring *adherence* to SOPs • Most logistics departments experience low *employee retention* rates • High *employee absenteeism* rates increases the workload for remaining staff
Employee work conditions	• *Challenging work conditions* - physically demanding, repetitive and ergonomically challenging *manual* work
Lead time	• One of the main challenges in the US bed logistics process is *delays* • *Balancing priorities* of calls is an issue
Value-added time	• *Physical constraints* - excessive transporting time to other building • *Delays* because of waiting time due to bottlenecks
Security of supply	• *Delays* - supplying a clean bed when occupancy is high in the US hospital • *Communication and information management* to ensure right bed, drug etc.
Environmental considerations	• *Excessive use of water* either through manual wash or automated wash

Traceability	• *Locating people and items:*
	  • The whereabouts of the beds is unknown
	  • Data on the history of the bed is not available
	  • Locating cleaning personnel is an issue in case B
	• Lack of *systems integration* makes it difficult to document process activities

Future proofing	• *Physical constraints:*
	  • The placement of the bed cleaning area increases transporting time for beds
	  • The pace of the monorail in the primary case hospital leads to inefficiencies in the process and the system is not easily replaced

Impact on related processes	• *Impact on related processes:*
	  • Increased work for related processes as a consequence of process changes
	  • Other staff groups must understand the importance of the logistics activities
	• *Collaborating with and educating other staff groups* for correct *handovers*

Degree of automation	• *Lack of data* availability due to lack of data logs • A significant amount of data is registered through *manual processes*

Information management	• *Lack of data*
	• *Communication and information management*:
	  • Difficulties in communicating right message
	  • Other staff groups must understand the importance of the logistics activities
	• Lack of *systems integration* makes it difficult to document process activities

Table 4.4. Challenges and impact factors identified only for US bed logistics case

Impact factors	Challenges
Compliance (US)	• *Adherence* to SOPs
Patient experience, care and safety (US)	• *Impact on related processes* - ensuring a clean bed within a certain time horizon affects patient experience
Cycle time (US)	• Driving out *variance* and ensuring that just enough time is spent on cleaning for *quality* assurance purposes
IT and physical infrastructure (US)	• *Systems integration* – it is a challenge to work in several systems that do not integrate

Challenges in the pharmaceutical distribution process

Challenges identified for the pharmaceutical distribution process are presented for the Danish and US hospitals.

Manual processes. Mostly an issue for the Danish pharmaceutical distribution case, a large part of the process is manual.

Product availability. Shortages in pharmaceutical supplies are an issue for US hospitals in general, including the US case hospital.

Stock count accuracy. For the US hospital, the stock was counted every two weeks to ensure stock count accuracy. This task is time consuming and could be automated by applying RFID technology.

Locating pharmaceutical products. Locating pharmaceuticals is mainly an issue for the Danish hospital. The lack of traceability for the Danish process has caused items to disappear and locating lost items is time consuming. In the US hospital, the location of a pharmaceutical product is always known due to the continuous registration of the location of a product through barcodes.

Problematic handovers. In the primary case hospital, it has not been possible to ensure the signature from clinical staff for receiving pharmaceutical items. However, in another Danish hospital, this was implemented after an extensive campaign to ensure that clinical departments would sign off for received items. However, for the US hospital, the problem of handovers lies in the lack of integration of internal systems.

Continuous education. An issue for the US process is how to cope with the continuous need for educating staff. Another aim of education is to change the culture toward a continuous improvement culture.

Capturing and analyzing data. Capturing data is mainly an issue for the Danish hospital, whereas the issue for the US hospital is to make sense of the extensive amount of available data to enable product mix and process optimization and high utilization of the technology.

Performance measurement. The difficulty in capturing data for the Danish process makes performance measurement challenging and consequently impossible to monitor the progress of process improvement initiatives. Traceability in the process would enable performance measurement to a larger extent.

Motivation. One manager in the inpatient pharmacy stated that "having happy employees is the most important thing… making sure that their job is meaningful". However, one of the challenges identified across the investigated case studies is the motivation of employees and ensuring employee engagement. Many of the tasks are repetitive and physically demanding. However, some of those tasks could potentially be automated.

Employee retention. As for the bed logistics and hospital cleaning processes, employee turnover is an issue the pharmaceutical distribution process, particularly for employees transporting items.

Employee absenteeism. Employee absenteeism is similarly an issue for the pharmaceutical distribution process, particularly for employees performing transport activities.

Control of the process. For a large part of the Danish process, products cannot be located. The Danish pharmaceutical distribution process is therefore much less controlled than its US counterpart. This is mainly due to the strict legislation for pharmaceutical products in the US and the available financial resources in the US hospital to invest in technologies such as barcodes.

Systems integration. The primary case hospital has not been able to integrate information systems with the regional warehouse to provide necessary reports.

Physical constraints. In the Danish hospital, the space allowed for repackaging pharmaceutical items is far from ideal with limited space and other ongoing activities within that same space. For the US hospital, a challenge is to balance limited space with the need for on-demand pharmaceutical products.

Maintenance. Particularly for the US pharmaceutical distribution process, maintaining central and particularly decentral technologies is a challenging and time consuming task.

Table 4.5 links the identified challenges to the derived impact factors, thereby linking data and codes.

Table 4.5. Challenges and impact factors identified for the pharmaceutical distribution cases

Impact factors	Challenges

Information management	• *Capturing and analyzing data:*
	  • Using available information to make critical decisions faster
	  • Using data to optimize the use of technologies
	  • Using data to ensure the right inventory mix
	• Enabling *performance measurement* to monitor process improvement progress

Risk of mistakes	• *Manual processes* - manually typing in quantities of received goods, especially because reorders are based on registered inventory for the US process • *Control of the process* - lack of control of the process, particularly in Denmark and the consequent risk of losing pharmaceutical products
Traceability	• *Control of the process* is enabled through traceability for the US case • *Problematic handovers* – traceability can help ensure accountability • *Performance measurement* is not possible for the Danish process, making it difficult to monitor any performance progress • Low *stock count accuracy* and risk of inventory shrinkage are particular issues for pharmaceutical distribution • *Locating pharmaceutical products* is not possible in the Danish case
Employee engagement	• *Continuous education* - changing the culture to sustain changes • *Employee absenteeism* is high • *Employee retention* is low

Competence match	• *Continuous education:*
	  • Changing the behavior of employees to learn new processes
	  • Changing the culture toward a continuous improvement culture

Security of supply	• *Product availability* from the supplier is a general issue for US hospitals
Downtime and maintenance (US)	• *Maintenance* is a challenge and may decrease the utilization of technologies in the short run, but will decrease utilization in the long run if not performed regularly • *Capturing and analyzing data* to increase the utilization of technologies
Utilization of technologies (US)	• *Maintenance* is a challenge and may decrease the utilization of technologies in the short run, but will decrease utilization in the long run if not performed regularly • *Capturing and analyzing data* to optimize the use of technologies

IT and Physical infrastructure (US)	• *Physical constraints:*
	  • May limit the opportunities for improvement
	  • Issue of balancing limited space with the need for on-demand drugs
	• *Systems integration* – to enable information sharing and creating a smooth process rather than working in several systems

In the following, the identified challenges are summarized for healthcare logistics processes as identified in the case studies.

Summary of challenges in healthcare logistics

Some of the challenges identified in the investigated case studies reoccur throughout all the cases. The reoccurring challenges relate to the following themes:

- Performance measurement
- Capturing data
- Employee retention
- Employee absenteeism
- Physical constraints
- Locating people and items
- Systems integration
- Problematic handovers

The identified challenges do not necessarily apply across all cases. E.g. some of the challenges experienced for the bed logistics cases do not apply for the pharmaceutical distribution cases and vice versa. Furthermore, it seems that what is perceived as a challenge for one hospital does not necessarily pose a challenge for other hospitals because of the interventions that have been implemented. In the following section, interventions identified for the case study processes are presented and best practices identified.

4.2 COMPARING INTERVENTIONS IN HEALTHCARE LOGISTICS

The interventions identified in each of the case studies are presented in the following together with reasons for implementation and observed benefits of the interventions. The interventions are divided into the categories BPM, logistics and SCM, technological interventions, and organizational interventions, according to the literature review. Each of the interventions is related to the identified impact factors, i.e. linking data to the codes used for analyzing the qualitative data. The identified impact factors will serve as decision criteria in the framework developed in this study. Furthermore, best practices are identified based on the interventions.

4.2.1 BPM

The BPM interventions identified for the investigated case studies are presented in the following. BPM interventions include any implemented changes relating to BPM, including changes to process steps and applied performance management.

Bed logistics and hospital cleaning

BPM interventions for the bed logistics process and hospital cleaning process are presented in the following. Table 4.6 provides an overview of the interventions and the related impact factors which were identified from qualitative data coding.

Table 4.6. BPM interventions and related impact factors for bed logistics and cleaning

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
SOP for cleaning process	In the US hospital, a 7-step process has been implemented to limit variance in the cleaning process and to ensure a consistent result that lives up to the cleaning requirements. This is ensured through training. In the Danish hospital, a SOP for cleaning has been implemented for quality assurance reasons.	• Consistency • Risk of mistakes • Output quality • Competence match • Patient experience, care and safety • Compliance
Quality check schemes	In both the Danish and US hospitals, a random sample of rooms were checked for quality assurance purposes.	• Consistency • Risk of mistakes • Output quality • Patient experience, care and safety • Compliance
Additional cleaning steps	One Danish hospital introduced additional cleaning steps to cope with quality issues.	• Output quality
Additional maintenance steps	One Danish hospital introduced additional maintenance steps to cope with quality issues.	• Output quality
Measuring performance	Performance was measured for both the Danish and US hospitals: Random sample quality reports for cleaning. Measuring lead time for patient transport. Measuring number of cleaned beds. Tracking progress of discharge beds (only US).	• Output quality • Consistency • Information management • Traceability
Service Express Center	The Service Express center is a one-stop-shop that has reduced the lead time for customers and has led to improved services.	• Lead time • Patient experience, care and safety
Service Level Agreements	Service level agreement have ensured accountability for performed services and changed the behavior of employees. Agreements with departments ensure that services live up to expectations.	• Lead time • Cycle time • Employee engagement • Output quality • Patient experience, care and safety

Pharmaceutical distribution

Similar to the bed logistics and hospital cleaning cases, the BPM improvement interventions identified for the pharmaceutical distribution cases are presented in Table 4.7 along with reasons for implementation and the associated and derived impact factors.

The interventions in Table 4.7 mainly relate to continuous improvement, handovers and quality assurance through service level agreements. Although service level agreements were in place in both Danish and US hospitals, the US hospital seemed more concerned with performance measurement than the Danish hospitals.

Table 4.7. BPM interventions and related impact factors for pharmaceuticals

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Continuous improvement	Continuous improvement has eliminated waste and created visibility for staff as well as ensured employee engagement in the US hospital.	• Employee engagement • Information management • Value-added time
Control measures at handovers	For the US process, every handover required controls that the correct items were handed over to the next process step and who was responsible and could be held accountable.	• Competence shifts • Risk of mistakes • Traceability • Information management
Sign off for received items	Signing off for received items in the US hospitals and at the receiving dock in the Danish hospital was implemented to document the process and for accountability reasons.	• Information management • Traceability • Competence shifts • Risk of mistakes
Service Level Agreements	In the US hospital, the automated medication dispensing stations are serviced at specific times of the day every day.	• Lead time • Output quality

4.2.2 Logistics and SCM interventions

The logistics and SCM interventions identified for each of the case studies are presented in the following. The bed logistics and hospital cleaning cases are treated in conjunction and the pharmaceutical distribution cases are treated separately.

Bed logistics and hospital cleaning

The logistics and SCM interventions for the bed logistics and hospital cleaning processes are listed in Table 4.8 along with reasons for implementation and related impact factors. As Table 4.8 shows, the SCM interventions mainly relate to centralization and decentralization of activities and inventories of beds.

Table 4.8. Logistics/SCM interventions and related impact factors for bed logistics and cleaning

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Centralized bed cleaning activities	The Danish hospitals centralized the bed cleaning task to enable a more thorough wash, thereby improving the output quality. This setup increases the number of beds needed, but reduces lead time for providing a clean room and bed for a new patient.	• Output quality • Consistency • Lead time
Centralized bed inventory	The Danish hospitals have centralized the bed inventory, i.e. beds are moved to the room where it is needed and when it is needed. This is connected to the decision of centralized bed cleaning.	• Lead time
Decentralized bed cleaning activities	The US hospital decentralized bed to increase efficiency of the process and avoid transport. This setup reduces the number of beds needed, but increases the lead time for providing a clean room and bed for a new patient.	• Unnecessary processes • Lead time
Decentralized bed inventory	The US hospital has decentralized the inventory of beds, i.e. all beds are fixed to a room. This is connected to the decision of decentralized bed cleaning.	• Lead time

Pharmaceutical distribution

The logistics and SCM interventions of the pharmaceutical distribution process identified for the Danish an US hospital are listed in Table 4.9 together with reasons for implementation and factors impacting the decision for implementation.

The identified interventions listed in Table 4.9 relate to inventory management and handling of emergency orders. Comparing the logistics and SCM interventions across process types, the interventions in the bed logistics and hospital cleaning processes relate to centralization and decentralization of activities and inventories. For the pharmaceutical distribution process, replenishment of supplies was a more dominant theme. This difference is most likely due to the nature of the flow, i.e. bed logistics is a closed-loop flow and not directly related to patient care, whereas pharmaceutical products are replenished by entering the hospital from an external supplier and “exiting” with the patient at the point of consumption and as part of the treatment.

Table 4.9. Logistics/SCM interventions and related impact factors for pharmaceuticals

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Stock reduction project	For the US hospital, inventory levels have been greatly reduced by analyzing the inventory mix.	• Value-added time
Central and decentralized inventories	The US hospital has implemented a centralized inventory to supply the decentralized inventories in the clinical departments. This has reduced stock levels, product mix and security of supply for the decentral inventories. The Danish hospital only has decentral inventories, which are replenished daily on week days.	• Security of supply • Lead time
Emergency orders	Both the US and Danish hospitals utilize the option to internally borrow products between departments. Both the US hospital and Danish hospital can make emergency orders from suppliers or from other hospitals/campuses.	• Security of supply • Lead time
Reorder points	Reorder points have been introduced for both the Danish and US hospitals to ensure availability of pharmaceutical products when needed and to reduce the stock levels.	• Security of supply • Lead time • Information management
Vendor managed inventory	VMI has not been implemented in the traditional sense, but for the Danish hospital, staff from the regional warehouse manages the pharmaceutical inventories in most wards.	• Security of supply • Lead time • Information management

4.2.3 Technological interventions

In this section, the technological interventions identified for each case study are reported. The technologies identified for bed logistics and hospital cleaning are treated together and the technologies identified for the pharmaceutical distribution process are treated in a subsequent section.

Bed logistics and hospital cleaning

No technology had been implemented for the Danish hospital cleaning case. The identified technologies for the bed logistics case are reported in separate tables for each hospital because they are so distinctly different. Technologies identified for the Danish hospital are listed in Table 4.10 and technologies for the US hospital are listed in Table 4.11.

Table 4.10. Technological interventions and related impact factors for Danish bed logistics

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Equipment to load and unload mattresses	The Danish hospitals had implemented equipment to alleviate employees from strenuous work. Some hospitals experienced issues with implementation as employees refused to use the equipment due to prolonged processing times. Another hospital could not use an implemented crane because it could not tolerate water.	• Employee work conditions
Monorail	To reduce the use of employee resources. Use staff when human attention is required.	• Degree of automation • Unnecessary process
Washing machine	One of the washing machines was chosen because it can wash several beds at a time. Washing beds with machines takes longer but produces cleaner beds. To reduce the use of water for washing beds. To ensure consistent output quality. To avoid mistakes in the process. A simple technological solution ensures ease of use for the employees. To use the washing machines for other tasks. To reduce the need for staff resources.	• Lead time • Environmental considerations • Consistency • Features and ease of use • Risk of mistakes • Impact on related processes • Output quality • Competence shifts • Unnecessary process
Mobile phones	Transporters were equipped with mobile phones to prioritize tasks, dispatch jobs and to monitor the progress of jobs.	• Information management • Traceability
(Barcodes)	Barcodes enable traceability of beds, data capturing, planning and continuous improvement.	• Traceability • Information management
(RFID)	Enables traceability of beds, data capturing, and planning. Using RFID to capture data is more automated than for barcodes. Capture data on beds, enable planning, study/improve the bed flow.	• Traceability • Degree of automation • Information management

Efforts to implement certain technologies had turned out in failure. E.g. for one Danish hospital, employees refused to use a crane in the process because of the prolonged processing time. For another Danish hospital, the implementation of similar equipment had failed because the equipment could not tolerate contact with water. Furthermore, RFID had only been tested in the Danish hospitals and were not used in day to day operations. Similarly, barcodes were only used to a limited extent and mainly for maintenance purposes. In some hospitals, further investments in software were necessary to fully utilize barcodes. RFID and barcodes are therefore in parentheses in Table 4.10.

Table 4.11. Technological interventions and related impact factors for US bed logistics

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Automated guided vehicles	Used in the US hospital for transporting linen. Response time is fast and the business case showed it was a financially viable solution. It also saves injuries as some carts are heavy.	• Lead time • Value-added time • Degree of automation • Employee work conditions
Admission and transfer logs	This system will be replaced by Epic at the US hospital, but it currently enables the bed management team to assign beds.	• Value-added time • Information management
Epic	In the US hospital, Epic holds the patient medical records and is also used for a small part of bed management. Soon all bed management will be done in Epic.	• Value-added time • Information management
Teletracking	In the US hospital, this system is used for documenting time stamps for discharge cleaning and for patient transports and cleaning discharge rooms.	• Information management • Traceability
Cleantrace technology	In the US hospital, this technology is used for measuring the bio burden on surfaces.	• Risk of mistakes • Output quality

In the Danish bed logistics process, few technologies had been implemented and were mainly implemented to alleviate physically hard work. The US bed logistics case had mainly implemented technologies enabling transportation and information systems for bed management and performance measurement purposes. The difference in technological interventions partly relates to differences in process design; the Danish process involves central cleaning, which allows for automation of the cleaning process, whereas the US process is decentralized and therefore cannot be automated. Another aspect, which could explain the differences, is that the US hospital seems more concerned with performance measurement than the Danish hospitals.

Pharmaceutical distribution

Apart from a system for ordering pharmaceutical products (EDI), all the identified technologies in the pharmaceutical case studies were identified in the US case study. The identified technologies, reasons for implementation and related impact factors are listed in Table 4.12.

Out of all the investigated cases, the pharmaceutical distribution process in the US is the most automated process. This is in sharp contrast to the Danish pharmaceutical case, which involves nearly no technologies. Comparing the technologies identified for the bed logistics and hospital cleaning processes with those identified for the pharmaceutical distribution process, the pharmaceutical distribution in the US involves technologies mainly related to inventory, track and trace, and transport. Barcodes and RFID are used to a larger extent for pharmaceutical distribution, whereas the bed logistics process mainly involves technologies related to transport, automated cleaning and information management.

Table 4.12**.** Technological interventions and related impact factors for US pharmaceutical case

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Automated guided vehicles	Used for transporting drugs to the pharmacy. Response time is fast and the business case showed it was a financially viable solution (also used for other transports). It saves injuries as some carts are heavy.	• Lead time • Degree of automation • Employee work conditions
Epic	Epic stores electronic medical records and drug records. The CPOEs (computerized physician order entry) and prescriptions are entered into Epic.	• Degree of automation • Value-added time • Information management
Pneumatic tubes	Pneumatic tubes are used for small drug transports in cases of emergency. Transport time is 10-20 minutes.	• Degree of automation • Lead time
Picking carousels	Automated carousels are used for picking drugs. The machine indicates which drawer in the carousel to pick from, and a technician then picks the drugs. This semi-automated solution allows for more flexibility in terms of capacity, i.e. adding employees to increase capacity.	• Degree of automation • Future proofing • Infrastructure
Medication dispensing stations	Ensures availability of drugs close to the patient and involves safety mechanisms for the patient.	• Security of supply • Compliance • Patient care, experience and safety
MRP system	An MRP system is used that enables inventory management, purchasing, and finance.	• Degree of automation • Information management
EDI (US and DK)	Enables automatic reordering of drugs.	• Degree of automation • Value-added time • Information management
Med boards	Med boards are visual boards that together with barcodes enable tracking of drugs – it is possible to see where the meds are at any particular moment in time.	• Traceability • Information management • Compliance
Barcodes	Barcodes are used for tracking drugs and for bedside verification. The patient's wristband and the drug are scanned for verification.	• Traceability • Information management • Compliance
RFID	Code boxes are tracked and localized through RFID technology.	• Traceability

Automation is not necessarily a goal in itself and as one manager in the Danish bed logistics case pointed out:

> Automation is important for improving efficiency. However, we must also think of the people working in these jobs – it will be difficult for them to find other jobs. I believe in future solutions that include both automation and people.

This statement alludes to the corporate social responsibility of an organization. Another argument supporting semi-automated solutions was provided by a pharmacy manager in the US hospital who noted that the semi-automated picking carousel was chosen because of its higher flexibility in capacity and the less space required compared to a fully automated solution.

4.2.4 Organizational interventions

In the following, the organizational interventions identified for the bed logistics and cleaning cases are presented in conjunction followed by a presentation of the identified organizational interventions for the pharmaceutical distribution cases.

Bed logistics and cleaning

The organizational interventions identified for the bed logistics and cleaning cases are presented in Table 4.13.

Table 4.13. Organizational interventions and related impact factors for bed logistics/cleaning

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Installing sense of pride	In one of the Danish hospitals, staff in bed cleaning would make the beds with crisp corners like for hotel beds. Managers had emphasized to the employees that their work was of the utmost importance for the care of patients, thus installing a sense of pride in the employees. The US hospital is a prestigious workplace and employees often feel proud to work there.	• Employee engagement
Continuous Improvement department	The US hospital has introduced a Continuous Improvement department, which is a physician driven matrix organization with centralized and decentralized continuous improvement staff. This ensures employee engagement, the elimination of unnecessary processes, more patient-focused processes, and timely delivery.	• Unnecessary process • Employee engagement • Patient care, experience and safety • Lead time
Centralized organization of transporters	The organization of transporters in Danish and US hospital is centralized. This has led to a higher resource utilization and faster response.	• Unnecessary process • Lead time
Centralized organization of (bed) cleaning staff	For both the US and Danish hospitals, the cleaning organization is centralized. Cleaning tasks may be decentralized, but the organization is centralized, i.e. departments are cleaned by a central unit, which operates all over the hospital. This ensures better utilization of resources and better response times.	• Unnecessary process • Lead time
Education	Cleaning and transport staff is carefully trained to perform tasks satisfactory.	• Competence match

The organizational interventions for bed logistics and hospital cleaning mainly relates to centralization of the organization and competence enhancement. For the Danish hospitals, logistics staff was often not able to see their individual contribution to the overall goals of the hospitals and the job was not necessarily viewed as a step toward a future career. One Danish hospital had made a particular effort to improve the employee sense of worth and for them to realize the contribution they make in the hospital. In comparison, the US hospital is viewed as a prestigious place to work and for some logistics employees a way to start a future career.

Pharmaceutical distribution

The organizational interventions identified for the pharmaceutical distribution cases in Denmark and the US are listed in Table 4.14. The interventions mainly relate to the organizational responsibility for managing pharmaceutical products and to enhancing competencies. For the Danish bed logistics case, one Danish hospital was particularly concerned with employees' feeling of worth and being valued by others. This is not much of an issue in the US hospital as it is considered a prestigious workplace. However, as one of the managers in the US pharmacy mentioned, it is an important task of a manager to ensure that employees are happy and have meaningful jobs. This approach to management also helps motivate employees.

Table 4.14. Organizational interventions and related impact factors for pharmaceutical cases

Intervention	Reasons for implementation and benefits	Associated and derived impact factors
Continuous Improvement department	The US hospital has introduced a Continuous Improvement department, which is a physician driven matrix department with centralized and decentralized continuous improvement staff. This ensures employee engagement, the elimination of unnecessary processes, more patient-focused processes, and timely delivery.	• Unnecessary process • Employee engagement • Patient care, experience and safety • Lead time
Centralized pharmacy organization	The US hospital has a centralized pharmacy from where pharmaceutical products are managed and distributed. This ensures internal competencies to manage pharmaceutical products and control of the process.	• Competence match • Information management
Third party inventory management	In the Danish hospital, pharmaconomists and pharmacists from the regional warehouse manage the inventory of the hospital in the hope of reducing stock levels, saving money and to focus on core competencies.	• Unnecessary process • Competence match
Education	To support and encourage a continuous improvement culture in the US hospital.	• Employee engagement

Out of all the interventions identified in previous sections, the best practices are discussed in the following section.

4.2.5 Best practices

In the following, the best practices identified in the case studies for each of the four types of interventions are discussed. The purpose of identifying best practices is to elucidate the best opportunities for managers to improve their processes, i.e. identifying a set of best practices, which are candidates for adoption (Sousa and Voss, 2001). The identified best practices provide a number of alternatives for improving healthcare logistics processes, which managers can then choose to implement or not. Whether to implement an intervention depends on the needs and preferences of the hospital and possible contingent factors, i.e. the circumstances under which an intervention is preferable. It may not be feasible to implement all the identified best practices and managers may therefore need to narrow down the number of interventions to be implemented. For selecting the interventions suitable for a particular hospital, a framework is developed in this thesis to guide decision makers in improving their processes. The impact factors relevant to each of the best practices are found in Table 4.6 to Table 4.14 in the previous sub-sections.

Although best practices were mostly expected from the US hospital, best practices were identified in both Danish and US cases. The best practices were selected based on the benefits experienced in the hospitals and the opinions of the interviewees. Thus, other best practices may exist outside of the case studies, e.g. as identified in literature or even practices which have not yet been reported in literature. Furthermore, some best practices may only apply in certain cases whereas other practices may apply under several different circumstances. The best practices are discussed according to each of the four types of interventions, i.e. BPM best practices, logistics and SCM best practices, technological best practices, and organizational best practices.

BPM best practices

The following BPM best practices were identified in the case studies:

- Performance measurement
- SOPs
- Reduce and control handovers
- Continuous improvement
- Manual processes when necessary

Performance measurement. Performance measurement was conducted in both the Danish and US hospitals and for all case studies. Although carried out to a lesser extent for the Danish bed logistics and hospital cleaning cases, these processes could benefit from more data capturing to enable performance measurement and to monitor performance progress.

SOPs. Standard operating procedures were identified for all cases, although in some cases they were followed more to the letter than others.

Reduce and control handovers. Apart from the hospital cleaning case, the investigated processes involve several handovers between staff groups. These handovers increase the risk of mistakes. Furthermore, handing over the responsibility of a task means that accountability shifts to another employee. It is therefore important to document who is responsible at what point in time.

Continuous improvement. Continuous improvement permeates the culture and organization of the entire US hospital. The continuous improvement approach ensures that process performance is continually improved and that processes are designed to create value for the patients. For the Danish hospitals, lean projects have been carried out throughout the region.

Manual processes. Although manual processes pose a number of challenges, some processes are best left in the hands of human resources. E.g. the transport of patients cannot be automated and must be carried out by trained staff to ensure patient safety. Similarly, cleaning must be performed by trained staff and is not easily automated due to the complexity of the process, i.e. the different types of surfaces that must be cleaned.

Logistics and SCM interventions

The following logistics and SCM best practices were identified in the cases:

- Reorder point
- Centralization vs. decentralization of activities
- Centralization vs. decentralization of inventory

Reorder point. A reorder point was set for both the Danish and US pharmaceutical distribution processes. Such a practice is mainly relevant for tangible items and for processes which are not closed-loop.

(De-)centralization of activities. Bed cleaning activities are centralized for the Danish hospitals and decentralized for the US hospital. The two setups are trade-

offs in terms of lead time and transport. The lead time for delivering a clean room for a new patient is short for the Danish hospital compared to the US hospital, but then requires transporting time for the bed to the central cleaning unit. Conversely, a room can only be released to a new patient in the US hospital after the room and bed has been cleaned, but then there is no transport time for the bed. In terms of quality, some would argue that quality is higher for the cleanliness of beds in the Danish hospitals because they can be cleaned using washing machines. Thus, the setup depends on the priorities of the hospital in terms of these trade-offs.

(De-)centralization of inventory. For bed logistics, the inventory of beds is centralized for the Danish case study and decentralized for the US case study. This difference can be attributed to the difference in process design in terms of centralized and decentralized cleaning activities, i.e. centralized cleaning in the Danish hospital and decentralized cleaning in the US hospital. For the hospital cleaning process, cleaning gear and products are managed centrally and are not stored locally in departments.

For the pharmaceutical distribution process, both Danish and US hospitals hold decentralized stock in the clinical departments. In addition, the US hospital holds central stock to supply the decentralized inventories. One reason for this difference could be the difference in hospital size in terms of beds and space, i.e. the US hospital is much larger and would require significantly more time to distribute pharmaceutical products directly upon arrival from the suppliers. Furthermore, such a setup would either require a massive amount of resources within a limited time span or coordinated deliveries throughout the day. Another reason for the centralized pharmacy in the US hospital is that buffer stock can be shared across units. Furthermore, a central pharmacy ensures more control of the process in adhering to the FDA rules. Another aspect to consider is that the Danish hospital has less capacity in terms of space and human resources. The decentralized inventories of the Danish hospital require fewer resources than a solution involving an additional central inventory. Thus, in this case, the regional warehouse serves as a warehouse for the Danish hospital to a larger extent than the suppliers do for the US hospital.

Technological best practices

The following technological best practices were identified in the cases:

- EDI

- Barcodes
- RFID
- Picking carousel
- AGVs
- Pneumatic tubes

EDI. Electronic data interchange enables hospitals to order products and make transactions through a secure line between the hospital and the supplier.

Barcodes. Barcode technology enables track and trace of items, although not in real-time. Furthermore, barcodes can capture data to enable performance measurement. The technology was mainly utilized in the US pharmaceutical distribution process but could be used for any type of process and in any country setting.

RFID. Depending on the technical specifications of the RFID solution and the placement of scanners, RFID technology can enable real-time track and trace of items and personnel and allow for continuous monitoring of processes. Furthermore, data capturing through RFID technology enables performance measurement. RFID was only used in the day to day operations of the US hospital and only to a limited extent. A wider use of RFIDs, e.g. for inventory management, could provide significant benefits, particularly to enhance stock accuracy and to automate the stock counting process.

Picking carousel. The semi-automated picking carousel is flexible and requires less space than a fully automated solution. Hospitals are often tight for space, and a semi-automated solution might be preferable in such a setting. Furthermore, a semi-automated solution is more flexible in terms of capacity. A picking carousel is only applicable for processes containing tangible items.

AGVs. Automated guided vehicles enable automated transportation of items across the hospital and operate at all hours of the day. For the economic justification of AGVs in the US hospital, a 30% absence rate for logistics staff was used to calculate financial benefits. AGVs will require downtime and maintenance, but can work all hours of the day. AGVs had not been implemented in any of the Danish hospitals, but were part of the expansion plan for the primary case hospital.

Pneumatic tubes. Pneumatic tubes enable fast transport of relatively small items. They can be operated all hours of the day to specific destinations included in the pneumatic tube system.

Organizational best practices

The following organizational best practices were identified in the cases:

- Continuous Improvement department
- Installing sense of pride
- Centralization vs. decentralization
- Education

Continuous Improvement department. One of the reasons for the continuous improvement culture permeating the entire organization of the US hospital is the physician driven Continuous Improvement department, which operates both centralized and decentralized in a type of matrix organization. The Continuous Improvement department is concerned with both patient treatment processes and non-treatment related processes such as administrative tasks and logistics processes. Furthermore, the organization offers a physician driven course in continuous improvement for certain employee groups. In these courses, employees must undertake a continuous improvement project for their department. In the hospital region of the Danish case hospitals, central and local lean and other types of improvement units are carrying out improvement projects.

Installing sense of pride. In one of the Danish hospitals, employees would make the beds with crisp corners as in a hotel. Furthermore, management had emphasized to the employees the importance of their work. This encouragement from management and sense of pride inherent in the process steps could be applicable to other processes than bed logistics and to other hospitals. In the US hospital, employees already feel proud of their work due to the prestige of working in that particular hospital.

(De-)centralized organization. For all the case studies, the logistics organization was centralized. Centralization of an organization increases the utilization of resources. E.g. transporters in the primary Danish case hospital used to serve their personally assigned departments. Now, transporters serve all departments. One transporter mentioned that a consequence of this change was that transporters felt less responsible for their work.

Education. For all the case studies, training was part of enhancing employee competencies. The cases showed that training should not only include logistics staff but also other staff groups such as clinical staff who engage with logistics processes in hospitals (P2 and P4). Furthermore, the case results show that staff competencies influence the quality of work (P2 and P4).

4.3 CONSOLIDATING IDENTIFIED IMPACT FACTORS

The impact factors identified in the previous sections of the Results chapter are categorized in the following. Furthermore, interrelations between impact factors are suggested based on the case studies.

4.3.1 CATEGORIZING THE IMPACT FACTORS

The identified impact factors are summarized in Table 4.15. The impact factors reflect the codes identified in the process of coding the qualitative data. The codes have been categorized according to the four constructs Logistics, Technology, Procedure and Structure as identified in the literature review.

Table 4.15. Identified and categorized impact factors

	Logistics	Technology	Procedure	Structure
DK Bed		• Environmental considerations*		
Denmark and US	• Lead time • Value-added time • Security of supply • Traceability	• Degree of automation • Information management • Features and ease of use • Downtime and maintenance	• Risk of mistakes • Consistency • Future proofing • Impact on related processes • Output quality	• Competence shifts • Competence match • Unnecessary process • Employee engagement • Employee work conditions
US	• Cycle time	• Infrastructure (IT and physical) • Utilization of technologies	• Compliance • Patient care, safety and experience	

Environmental considerations were identified for the Danish bed logistics case study, but were not relevant for selecting track and trace technologies in the Danish hospital cleaning case (P3) nor in the Danish pharmaceutical distribution case. Furthermore, *environmental considerations* as decision criterion was not found to be relevant for the US cases. Conversely, some impact factors were only identified for the US hospital. However, as these impact factors were not validated for the Danish setting due to the sequence of the case studies, these impact factors may still apply to a Danish context. Thus, *cycle time* could apply to the Danish hospital as it is closely related to lead time and value-added time. Furthermore, *infrastructure* is particularly relevant for Danish hospitals in terms of physical infrastructure and physical limitations, e.g. the separate area for cleaning beds and necessary space for reorganizing pharmaceutical packages in the primary case hospital. *Utilization of technologies* applies to the primary Danish case hospital for the current setup and for justifying the implementation of new technologies. *Compliance* relates to compliance to internal policies and external regulations, which will also be an issue in Danish hospitals. *Patient care, safety and experience* relates to the experiences of the ultimate customer, i.e. the patient. A description of all the identified impact factors is found in Table 4.16.

Table 4.16. Description of impact factors across all cases

	Impact factors	**Description**
Logistics	*Lead time*	Time elapsed from order to delivery, i.e. what the customer experiences.
	Value-added time	% of lead time adding value to the customer.
	Security of supply	Ensuring the right amount at the right time.
	Traceability	Enabling track and trace of the whereabouts of items and people.
	Cycle time	Cycle time includes processing time and delays.
Technology	*Environmental considerations*	Sustainable use of energy, chemicals, renewable materials etc.
	Degree of automation	How automated is the process?
	Information management	The ability to collect, analyze and communicate data.
	Features and ease of use	The features of a technology and the ease of use for employees.
	Downtime and maintenance	Expected downtime and necessary maintenance for a given technology.
	Infrastructure	Infrastructure relates to both physical and IT infrastructure. IT infrastructure is necessary to enable the use of software to manage the processes. Physical infrastructure relates to the physical constraints of a building.
	Utilization of technologies	Potential application of a technology and utilization in terms of capacity.
Procedure	*Risk of mistakes*	Likelihood of mistakes occurring.
	Consistency	Standardization of the process and process output.
	Future proofing	Will the solution sustain in five years' time? Is it flexible?
	Impact on related processes	Negative and positive impact on other processes. E.g. other use for technology or increased workload for others.
	Output quality	Quality of product/service delivered, i.e. how good is the product.
	Compliance	Complying with internal policies, procedures and legal requirements.
	Patient care, experience and safety	The quality and experience of the care and treatment patients undergo and the safety of the patient throughout the treatment.
Structure	*Competence shifts*	Number of handovers in the process.
	Competence match	Do the competencies of the employees match the needs of the process or is training needed?
	Unnecessary process	Can the process be avoided? I.e. could fewer resources suffice?
	Employee engagement	Is the employee motivated to perform the job? Is an incentive provided?
	Employee work conditions	Employee safety, work load, strenuous work, ergonomics, and the physical and psychological work environment.

In addition to categorizing the impact factors according to Logistics, Technology, Structure and Procedure, the impact factors can be divided into efficiency and effectiveness to reflect performance. As previously mentioned, efficiency is input oriented and considers the economic use of resources, i.e. "doing things the right way". Effectiveness is output oriented and considers the extent to which goals have been achieved, i.e. "doing the right thing" (Gleason and Barnum, 1982; Mentzer and Konrad, 1991; Neely et al., 2005). Table 4.17 shows how each impact factor relates to efficiency and effectiveness, respectively.

Table 4.17. Categorizing impact factors in terms of efficiency and effectiveness

	Logistics	**Technology**	**Procedure**	**Structure**
Efficiency	• Lead time • Value-added time • Cycle time	• Degree of automation • Downtime and maintenance • Features and ease of use • Utilization of technologies • Infrastructure (IT and physical)	• Risk of mistakes • Consistency • Future proofing	• Competence shifts • Competence match • Unnecessary process
Effectiveness	• Security of supply • Traceability	• Information management • Environmental considerations	• Impact on related processes • Output quality • Compliance • Patient care, safety and experience	• Employee engagement • Employee work conditions

In the following, arguments are provided for the categorization of each impact factor in terms of efficiency and effectiveness. The impact factors relating to efficiency are discussed first. *Lead time*, *value-added time* and *cycle time* are categorized as efficiency. A reduction in any of these measures whilst using the same resources would lead to a better use of resources within a shorter amount of time. However, *lead time* and *value-added time* could also be viewed as effectiveness in terms of quality and creating value for the patient. *Degree of automation* is categorized as efficiency because automation can lead to faster production in a large scale. *Downtime and maintenance* disrupts production and leads to poor utilization of technologies. However, regular maintenance is necessary to prolong the life of a technology. *Features and ease of use* means that a technology is easier to use for employees and provides features that may increase efficiency, i.e. automation. *Utilization of technologies* reflects a higher utilization of a given resource, i.e. efficiency increases. *Infrastructure*, which in this case can refer to both IT infrastructure and physical infrastructure, relates to "doing things the right way", i.e. efficiency. *Risk of mistakes* somehow relates to quality, but is categorized as an efficiency measure because mistakes require rework and hence more resources to perform a given task. *Consistency* relates to "doing things the right way" and reflects an efficiency measure, although *consistency* is also related to quality. *Future proofing* reflects "doing things right" in the long run, i.e. is this a sustainable solution for the next many years? *Competence shifts*, i.e. handovers, take time and may cause mistakes and consequently rework, thus decreasing efficiency. *Competence match* refers to the required skills to perform a task; lack of competencies may increase the time needed for an employee to perform a task and could lead to mistakes requiring rework, thus decreasing efficiency. *Unnecessary process* is a process that could be eliminated and reduce the resources needed to perform a task.

The impact factors relating to effectiveness will be discussed in the following. *Security of supply* means that customers or patients will be able to receive the needed service or item, i.e. the output. *Traceability* does not relate to the economic use of resources but rather the goal of controlling the process and ensuring accountability in a process. *Information management* may enable the efficient use of resources through the analysis of captured data, but as such is an enabler of achieving a goal. *Environmental considerations*, some would argue, is consistent with the economic use of resources. However, in this case, additional aspects such as chemicals and effects on the environment are to be considered. *Output quality* refers to producing a better output, i.e. in terms of customer needs. *Compliance* could be viewed as "doing things right", although in this case "doing things right" would not necessarily mean an economic use of resources, hence leading to an effectiveness categorization. *Patient care, safety and experience* reflects the overall goals of a hospital and therefore reflects effectiveness. *Employee work conditions* does not relate to the economic use of resources but may increase the use of resources to provide better conditions for employees and is therefore an effectiveness measure. *Impact on related processes* relates to the overall goals of the organization rather than the efficiency of a single unit. *Employee engagement* relates to achieving a goal of satisfied employees.

Some of the impact factors could relate to both efficiency and effectiveness. The arguments laid out reflect how each impact factor was understood for this study. Other views may prevail, but most importantly, the impact factors can be related to either efficiency or effectiveness and as such reflect an aspect of performance. Thus, the impact factors can be used for performance measurement and benchmarking purposes.

4.3.2 SUGGESTED RELATIONS BETWEEN IMPACT FACTORS

The identified impact factors each relate to one of the following constructs: Logistics (L), Technology (T), Procedure (P) or Structure (S). Relations between the impact factors were suggested based on the case studies. These relations were initially identified for the Danish bed logistics case study (see also P5) and consequently do not include impact factors only identified for the US cases. The relations are found in Table 4.18. The proposed relations need further validation, but additional evidence is found in the remaining case studies (see Appendix E).

Table 4.18. Suggested relations between impact factors

Effect of	Effect on	Nature of effect
Technology (T) vs. Procedure (P)		
Features and ease of use (T)	Output quality (P)	+
	Effect on related processes (P)	+/-
Degree of automation (T)	Risk of mistakes (P)	+
	Consistency (P)	+
Technology (T) vs. Structure (S)		
Degree of automation (T)	Employee work conditions (S)	+
	Unnecessary processes (S)	+
	Competence shifts (S)	+
Features and ease of use (T)	Employee engagement (S)	+/-
	Competence match (S)	+/-
Information management (T)	Employee engagement (S)	+/-
Technology (T) vs. Logistics (L)		
Traceability (L)	Enables information management (T)	+
Features and ease of use (T)	Lead time (L)	+/-
Downtime & maintenance (T)	Value-added time (L)	-
	Security of supply (L)	-
Procedure (P) vs. Logistics (L)		
Risk of mistakes (P)	Value-added time (L)	-
	Security of supply (L)	-
Improved output quality (P)	Value-added time (L)	+
	Lead time (L)	-
Structure (S) vs. Logistics (L)		
Unnecessary processes (S)	Value-added time (L)	-
	Lead time (L)	-
Competence shifts (S)	Value-added time (L)	-
	Lead time (L)	-
Competence match (S)	Value-added time (L)	+
	Lead time (L)	+
Traceability (L)	Competence shifts (S)	+
Structure (S) vs. Procedure (P)		
Competence shifts (S)	Risk of mistakes (P)	-
	Consistency (P)	+/-
Competence match (S)	Risk of mistakes (P)	
	Consistency (P)	+
	Output quality (P)	+
Employee engagement (S)	Output quality (P)	+
	Risk of mistakes (P)	+

The nature of the identified effects between impact factors, i.e. whether the effect of the impact factor is positive (+) or negative (-) is indicated in the far right column of Table 4.18. The identified effects can be consolidated into a simplified model as depicted in Figure 4.7.

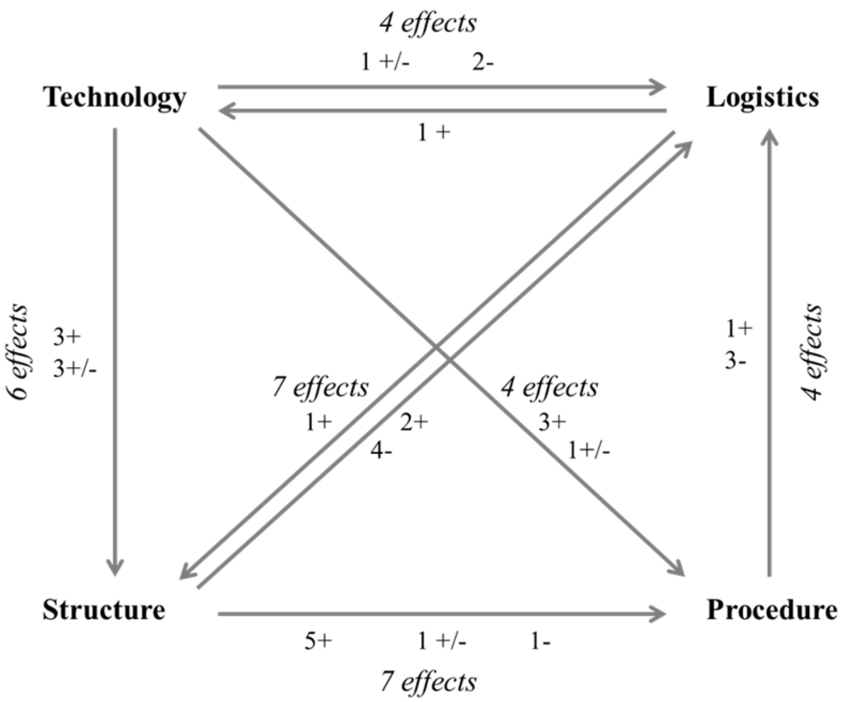

Figure 4.7. Consolidated effects identified in case studies. Source: P5.

The effects indicated in Table 4.18 and illustrated in Figure 4.7 suggest that Logistics and Procedure related factors are influenced the most by other factors, i.e. 13 effects and 11 effects, respectively; whereas factors relating to Structure and Technology influence other impact factors the most, i.e. 13 effects each. These effects need further validation, but they do suggest that in terms of decision making, effects between Technology, Logistics, Structure and Procedure will occur and should be taken into consideration. This aspect of decision making is elaborated later in the Results. Furthermore, the identified effects indicate that organizational interventions and technological interventions will affect other aspects of a healthcare logistics system the most.

4.4 Comparing impact factors across cases

For the Danish bed logistics case, US bed logistics case and US pharmaceutical distribution case, seventeen impact factors were identified and ranked as decision criteria according to the importance for improving healthcare logistics processes.

Five respondents from the Danish bed logistics case, three respondents from the US bed logistics case and two respondents from the US pharmaceutical distribution case assigned values on a 0-10 scale. The Danish pharmaceutical distribution case was not ranked on a 0-10 scale but by using the ANP method. Table 4.19 shows the average (μ) and standard deviation (σ) for each case and across all respondents. The table is sorted according to the average of all respondents, i.e. the far right column. The Danish pharmaceutical distribution case is not included in Table 4.19 as the impact factors were ranked using a different method. Horizontal lines indicate the top five and bottom five factors. For the most part, the standard deviation increases as the average decreases, i.e. there seems to be more consensus regarding high ranking factors than low ranking factors.

Table 4.19. Decision criteria weighted by the five Danish hospitals and the US hospital

	DK bed logistics case		US bed logistics case		US Pharmaceutical distribution case		All respondents	
# respondents:	*5*		*3*		*2*		*10*	
Impact factor	**μ**	**σ**	**μ**	**σ**	**μ**	**σ**	**μ**	**σ**
Output quality	9.8	0.5	9.0	1.7	9.5	0.7	9.4	1.0
Consistency	9.4	1.3	9.3	0.6	9.5	0.7	9.4	1.0
Employee engagement	9.4	1.3	9.7	0.6	9.0	1.4	9.4	1.1
Risk of mistakes	10.0	0.0	8.0	2.6	10.0	0.0	9.4	1.6
Security of supply	9.4	1.3	8.7	2.3	10.0	0.0	9.3	1.5
Information management	8.4	1.8	9.3	1.2	10.0	0.0	9.0	1.5
Employee work conditions	9.6	0.9	8.7	2.3	8.0	2.8	9.0	1.7
Lead time	8.4	2.6	8.7	1.5	8.5	2.1	8.5	2.0
Traceability	7.4	3.3	9.3	0.6	10.0	0.0	8.5	2.5
Value-added time	8.5	2.1	8.3	2.1	8.0	2.8	8.4	2.0
Impact on related processes	8.3	2.0	9.0	1.0	5.0	0.0	7.9	2.1
Unnecessary process	6.3	2.8	8.3	1.5	8.0	2.8	7.3	2.3
Competence shift	5.6	3.9	9.0	1.0	8.5	2.1	7.2	3.2
Future proofing	8.0	2.4	6.3	4.0	5.5	0.7	7.0	2.7
Competence match	5.6	4.2	8.3	1.5	8.0	2.8	6.9	3.3
Degree of automation	7.8	1.6	5.7	4.5	5.5	0.7	6.7	2.7
Environmental considerations	9.0	1.4	5.3	3.1	1.5	0.7	6.4	3.5

The top five impact factors across all respondents are 1) *output quality*, 2) *consistency*, 3) *employee engagement*, 4) *risk of mistakes* and 5) *security of supply*. Thus, three of the top five factors relate to quality, i.e. *output quality*, *consistency* and *risk of mistakes.*

The bottom five impact factors across all respondents were identified as 1) *competence shifts,* 2) *future proofing*, 3) *competence match*, 4) *degree of automation*, and 5) *environmental considerations*. Especially *competence shifts* and *competence match* seem to be under evaluated. As P4 suggests, competence shifts and competence match significantly impact quality and therefore should receive more attention. *Environmental considerations* does not seem to be a concern for the US hospital. Differences between cases and country settings will be investigated further in the following sections.

4.4.1 Comparison of Danish cases

The impact factors ranked for the Danish case studies are listed in Table 4.20. The individual responses to the Danish bed logistics case are reported together with the calculated average (μ) and standard deviation (σ). The individual responses ranking the impact factors in the Danish bed logistics case are divided according to the level of technology adoption, i.e. low (L), medium (M) and high (H) (see P2). The results show that only *degree of automation* depends on the level of technology adoption (P2). For the pharmaceutical process, the impact factors were ranked using the ANP method. The results of the ANP method can be found in the far right column of Table 4.20.

Table 4.20. Ranking of impact factors for Danish cases

	DK bed logistics case								DK pharmaceutical case	
	Hospitals (H1-H5)					*# respondents:*	*5*		*# respondents:*	*1*
	H3 (L)	**H1 (M)**	**H4 (M)**	**H5 (M)**	**H2 (H)**	**Impact factor**	**μ**	**σ**	**Impact factor**	**Priority**
Risk of mistakes	10	10	10	10	10	Risk of mistakes	10.0	-	Info management	1
Employee work conditions	10	8	10	10	10	Output quality	9.8	0.5	Output quality	0.44
Consistency	10	7	10	10	10	Employee work conditions	9.6	0.9	Security of supply	0.43
Employee engagement	10	7	10	10	10	Employee engagement	9.4	1.3	Employee engagement	0.40
Security of supply	10	7	10	10	10	Consistency	9.4	1.3	Risk of mistakes	0.37
Environmental considerations	10	7	10	8	10	Security of supply	9.4	1.3	Value-added time	0.33
Value-added time	9	5	10	8	10	Environmental considerations	9.0	1.4	Lead time	0.24
Lead time	10	4	10	8	10	Value-added time	8.5	2.1	Competence shift	0.22
Information management	10	5	10	9	8	Information management	8.4	1.8	Employee work conditions	0.18
Impact on related processes	10	5	8	9	10	Lead time	8.4	2.6	Unnecessary process	0.16
Future proofing	9	4	8	10	10	Impact on related processes	8.3	2.0	Consistency	0.14
Output quality	10	9	(-)	10	10	Future proofing	8.0	2.4	Impact on rel. proc.	0.05
Degree of automation	9	6	7	7	10	Degree of automation	7.8	1.6	Competence match	0.05
Traceability	8	7	10	10	2	Traceability	7.4	3.3	Traceability	-
Competence shift	10	2	8	7	1	Unnecessary process	6.3	2.8	Future proofing	-
Comp. match	4	3	10	10	1	Competence shift	5.6	3.9	Degree of automat.	-
Unnecessary process	9	3	8	(-)	5	Competence match	5.6	4.2	Environmental considerations	-

Note that the calculated average for *output quality* calculated in Table 4.20 does not include the response of Hospital 4 because the assigned value of "0" was not consistent with the focus on quality (see P2 for details). For the same reason, the value of "0" for *unnecessary process* was not included in the average as this value did not seem to reflect the actual perceived importance (P2).

For the Danish bed logistics case and the Danish pharmaceutical distribution case, three impact factors reoccur in the top five ranked factors: 1) *risk of mistakes*, 2) *output quality*, and 3) *employee engagement*. For the Danish bed logistics case, *employee work conditions* and *consistency* are ranked high. For the Danish pharmaceutical distribution case, *information management* and *security of supply* also rank high.

Out of the bottom five ranked impact factors, *degree of automation*, *traceability* and *competence match* occur for both case studies. In addition, *unnecessary process* and *competence shifts* rank low for the bed logistics process, and *future proofing* and *environmental considerations* rank low for the pharmaceutical distribution case.

4.4.2 Comparison of US cases

For the US cases, the following additional impact factors were identified and ranked:

- Patient care, experience and safety
- Compliance
- Cycle time
- Infrastructure
- Utilization of technologies
- Features and ease of use
- Downtime and maintenance

Infrastructure refers to both IT related and physical infrastructure. *Features and ease of use* and *downtime and maintenance* were also indicated in the Danish bed logistics case study (see P5) but had not been ranked.

Table 4.21 shows how the US hospital ranked both new and previously identified impact factors. In the column on the far right, factors are ranked by assigning equal weights to the results from both US cases. An average for all respondents would skew the results toward the US bed logistics case because there are more respondents. Assigning equal weights to the results from both cases provides a more balanced view of the overall ranking of impact factors for US cases. The factors only ranked by the US hospital are indicated with a “*”.

Table 4.21. Ranking of impact factors for US cases

US bed logistics case			US pharmaceutical distribution case			US cases (equal weights)		
# respondents:	*3*		*# respondents:*	*2*		*# respondents:*	*5*	
Impact factor	**μ**	**σ**	**Impact factor**	**μ**	**σ**	**Impact factor**	**μ**	**σ**
Patient care, experience and safety*	10.0	-	Information management	10.0	-	Patient care, experience and safety*	9.8	0.4
Employee engagement	9.7	0.6	Traceability	10.0	-	Information mgmt.	9.7	0.5
Cycle time*	9.7	0.6	Compliance *	10.0	-	Traceability	9.7	0.5
Information management	9.3	1.2	Security of supply	10.0	-	Compliance *	9.7	0.5
Traceability	9.3	0.6	Risk of mistakes	10.0	-	Consistency	9.4	0.1
Compliance *	9.3	1.2	Patient care, experience and safety*	9.5	0.7	Employee engagement	9.3	0.5
Consistency	9.3	0.6	Consistency	9.5	0.7	Cycle time*	9.3	0.9
Output quality	9.0	1.7	Output quality	9.5	0.7	Security of supply	9.3	0.5
Competence shift	9.0	1.0	Employee engagement	9.0	1.4	Output quality	9.3	0.4
Infrastructure*	9.0	1.0	Cycle time*	9.0	1.4	Risk of mistakes	9.0	1.4
Utilization of technologies*	9.0	1.0	Competence shift	8.5	2.1	Competence shift	8.8	0.4
Impact on related processes	9.0	1.0	Infrastructure*	8.5	2.1	Infrastructure*	8.8	0.4
Security of supply	8.7	2.3	Lead time	8.5	2.1	Lead time	8.6	0.1
Lead time	8.7	1.5	Utilization of technologies*	8.0	2.8	Utilization of technologies*	8.5	0.7
Employee work conditions	8.7	2.3	Employee work conditions	8.0	2.8	Employee work conditions	8.3	0.5
Value-added time	8.3	2.1	Value-added time	8.0	2.8	Value-added time	8.2	0.2
Unnecessary process	8.3	1.5	Unnecessary process	8.0	2.8	Unnecessary process	8.2	0.2
Competence match	8.3	1.5	Competence match	8.0	2.8	Competence match	8.2	0.2
Risk of mistakes	8.0	2.6	Features and ease of use*	7.5	3.5	Features and ease of use*	7.8	0.4
Features and ease of use*	8.0	1.0	Downtime and maintenance*	6.5	2.1	Impact on related processes	7.0	2.8
Future proofing	6.3	4.0	Future proofing	5.5	0.7	Future proofing	5.9	0.6
Degree of automation	5.7	4.5	Degree of automation	5.5	0.7	Degree of automation	5.6	0.1
Environmental considerations	5.3	3.1	Impact on related processes	5.0	-	Downtime and maintenance*	5.6	1.3
Downtime and maintenance*	4.7	4.7	Environmental considerations	1.5	0.7	Environmental considerations	3.4	2.7

Table 4.21 shows that only *information management* and *traceability* appear in the top five list for both US cases. In addition, the following three impact factors rank relatively high for both cases: 1) *patient care*, *experience and safety*, 2) *compliance* and 3) *consistency*.

The lowest ranking impact factors include 1) *features and ease of use*, 2) *future proofing*, 3) *degree of automation*, 4) *environmental considerations*, 5) *downtime* *and maintenance* and 6) *impact on related processes*. As indicated in the US pharmaceutical distribution case, automation is not necessarily desirable, hence *degree of automation* ranks low as decision criterion. Furthermore, *environmental considerations* do not seem to be a concern in the US hospital.

4.4.3 Comparison of US and Danish cases

In the following, comparisons are made based on the country setting. Only the 17 factors ranked by Danish and US hospitals are compared, see Table 4.22.

Table 4.22. Comparison of Danish and US ranking of impact factors

DK bed logistics case			**DK pharmaceutical distribution**		**US cases (equal weights)**		
# respondents:	*5*		*# respondents:*	*1*	*# respondents:*	*5*	
Impact factor	**μ**	**σ**	**Impact factor**	**Priority**	**Impact factor**	**μ**	**σ**
Risk of mistakes	10.0	-	Information management	1	Information mgmt.	9.7	0.5
Output quality	9.8	0.5	Output quality	0.44	Traceability	9.7	0.5
Employee work conditions	9.6	0.9	Security of supply	0.43	Consistency	9.4	0.1
Employee engagement	9.4	1.3	Employee engagement	0.40	Employee engagement	9.3	0.5
Consistency	9.4	1.3	Risk of mistakes	0.37	Security of supply	9.3	0.5
Security of supply	9.4	1.3	Value-added time	0.33	Output quality	9.3	0.4
Environmental considerations	9.0	1.4	Lead time	0.24	Risk of mistakes	9.0	1.4
Value-added time	8.5	2.1	Competence shift	0.22	Competence shift	8.8	0.4
Information management	8.4	1.8	Employee work conditions	0.18	Lead time	8.6	0.1
Lead time	8.4	2.6	Unnecessary process	0.16	Employee work conditions	8.3	0.5
Impact on related processes	8.3	2.0	Consistency	0.14	Value-added time	8.2	0.2
Future proofing	8.0	2.4	Impact on related processes	0.05	Unnecessary process	8.2	0.2
Degree of automation	7.8	1.6	Competence match	0.05	Competence match	8.2	0.2
Traceability	7.4	3.3	Traceability	-	Impact on related processes	7.0	2.8
Unnecessary process	6.3	2.8	Future proofing	-	Future proofing	5.9	0.6
Competence shift	5.6	3.9	Degree of automation	-	Degree of automation	5.6	0.1
Competence match	5.6	4.2	Environmental considerations	-	Environmental considerations	3.4	2.7

The three reoccurring impact factors for the Danish case studies are: 1) *risk of mistakes*, 2) *output quality*, and 3) *employee engagement*. These are not consistent with any of the top five impact factors for the US cases in Table 4.22. Thus, it seems that there are more consensuses within the same country setting than within the same process type across borders.

For the Danish case studies, *degree of automation*, *traceability* and *competence match* are ranked in the bottom five impact factors. Similarly, *degree of automation* and *competence match* are ranked low for the US cases. However, *traceability* is one of the highest ranking impact factors for the US cases. This difference is most likely due to the strict rules and requirements of the FDA in US hospitals.

Thus, there seems to be some differences in the prioritization of impact factors across cases.

4.4.4 Comparison of bed logistics cases

The Danish and US bed logistics cases are compared in Table 4.23. The average (μ) and standard deviation (σ) for each case has been calculated. To rank the impact factors across both case studies, equal weights are assigned to the results of each case study to calculate an overall average.

Table 4.23. Ranking of impact factors for bed logistics cases

DK bed logistics case			**US bed logistics case**			**US and DK bed logistics cases (equal weights)**		
# respondents:	*5*		*# respondents:*	*3*		*# respondents:*	*8*	
Impact factor	**μ**	**σ**	**Impact factor**	**μ**	**σ**	**Impact factor**	**μ**	**σ**
Risk of mistakes	10.0	-	Employee engagement	9.7	0.6	Employee engagement	9.5	0.2
Output quality	9.8	0.5	Consistency	9.3	0.6	Output quality	9.4	0.5
Employee work conditions	9.6	0.9	Information management	9.3	1.2	Consistency	9.4	-
Employee engagement	9.4	1.3	Traceability	9.3	0.6	Employee work conditions	9.3	0.7
Consistency	9.4	1.3	Output quality	9.0	1.7	Security of supply	9.3	0.5
Security of supply	9.4	1.3	Impact on related processes	9.0	1.0	Risk of mistakes	9.1	1.4
Environmental considerations	9.0	1.4	Competence shift	9.0	1.0	Information management	8.8	0.7
Value-added time	8.5	2.1	Employee work conditions	8.7	2.3	Impact on related processes	8.6	0.5
Information management	8.4	1.8	Security of supply	8.7	2.3	Lead time	8.5	0.2
Lead time	8.4	2.6	Lead time	8.7	1.5	Value-added time	8.5	0.1
Impact on related processes	8.3	2.0	Value-added time	8.3	2.1	Traceability	8.1	1.4
Future proofing	8.0	2.4	Unnecessary process	8.3	1.5	Competence shift	7.6	2.4
Degree of automation	7.8	1.6	Competence match	8.3	1.5	Unnecessary process	7.4	1.5
Traceability	7.4	3.3	Risk of mistakes	8.0	2.6	Future proofing	7.1	1.2
Unnecessary process	6.3	2.8	Future proofing	6.3	4.0	Environmental considerations	7.0	2.6
Competence shift	5.6	3.9	Degree of automation	5.7	4.5	Competence match	6.9	1.9
Competence match	5.6	4.2	Environmental considerations	5.3	3.1	Degree of automation	6.6	1.5

Three impact factors reoccur for both bed logistics cases: 1) *Output quality*, 2) *employee engagement*, and 3) *consistency*. In addition, *employee work conditions* and *security of supply* occur for the consolidated ranking where both cases are assigned equal weights.

The impact factors reoccurring as least important for bed logistics cases include *degree of automation* and *competence match*. However, the case studies show that *competence match* significantly impacts the *output quality* of a process, suggesting that more focus on *competence match* is needed. As previously noted, *degree of automation* is not necessarily desirable, which the ranking reflects.

4.4.5 Comparison of pharmaceutical distribution cases

The ranking of impact factors for the Danish and US pharmaceutical cases are compared in Table 4.24.

Table 4.24. Ranking of impact factors for pharmaceutical distribution cases

DK pharmaceutical distribution case		US pharmaceutical distribution case		
# respondents:	*1*	*# respondents:*	*2*	
Impact factor	**Priority**	**Impact factor**	**μ**	**σ**
Information management	1	Information management	10.0	-
Output quality	0.44	Traceability	10.0	-
Security of supply	0.43	Security of supply	10.0	-
Employee engagement	0.40	Risk of mistakes	10.0	-
Risk of mistakes	0.37	Consistency	9.5	0.7
Value-added time	0.33	Output quality	9.5	0.7
Lead time	0.24	Employee engagement	9.0	1.4
Competence shift	0.22	Competence shift	8.5	2.1
Employee work conditions	0.18	Lead time	8.5	2.1
Unnecessary process	0.16	Employee work conditions	8.0	2.8
Consistency	0.14	Value-added time	8.0	2.8
Impact on related processes	0.05	Unnecessary process	8.0	2.8
Competence match	0.05	Competence match	8.0	2.8
Traceability	-	Future proofing	5.5	0.7
Future proofing	-	Degree of automation	5.5	0.7
Degree of automation	-	Impact on related processes	5.0	-
Environmental considerations	-	Environmental considerations	1.5	0.7

For the pharmaceutical distribution cases, *information management*, *security of supply*, *employee engagement* and *risk of mistakes* are present in the top five lists of both the Danish and US case studies. Furthermore, there is consensus among the two case studies that *competence match*, *future proofing*, *degree of automation* and *environmental considerations* are of low importance for improving the pharmaceutical distribution process. However, a notable difference between the two cases is *traceability* as a low ranking impact factor for the Danish case study and a high ranking impact factor for the US case study.

4.4.6 Comparison of bed logistics and pharmaceutical distribution cases

Table 4.25 compares the ranking of impact factors across the bed logistics and pharmaceutical distribution cases. The respondents for the pharmaceutical cases agree that *information management*, *security of supply*, *employee engagement* and *risk of mistakes* are important for the improvement of logistics processes. For the bed logistics cases, the top five impact factors similarly include *employee* *engagement* and *security of supply*. Thus, *employee engagement* and *security of supply* are of high importance for both bed logistics cases and pharmaceutical distribution cases.

Table 4.25. Comparison of bed logistics and pharmaceutical case ranking of impact factors

US and DK bed logistics cases (equal weights)			Pharmaceutical distribution case DK		Pharmaceutical distribution case US		
# respondents:	*8*		*# respondents:*	*1*	*# respondents:*	*2*	
Impact factor	**µ**	**σ**	**Impact factor**	**Priority**	**Impact factor**	**µ**	**σ**
Employee engagement	9.5	0.2	Information management	1.00	Information management	10.0	-
Output quality	9.4	0.5	Output quality	0.44	Traceability	10.0	-
Consistency	9.4	-	Security of supply	0.43	Security of supply	10.0	-
Employee work conditions	9.3	0.7	Employee engagement	0.40	Risk of mistakes	10.0	-
Security of supply	9.3	0.5	Risk of mistakes	0.37	Consistency	9.5	0.7
Risk of mistakes	9.1	1.4	Value-added time	0.33	Output quality	9.5	0.7
Information management	8.8	0.7	Lead time	0.24	Employee engagement	9.0	1.4
Impact on related processes	8.6	0.5	Competence shift	0.22	Competence shift	8.5	2.1
Lead time	8.5	0.2	Employee work conditions	0.18	Lead time	8.5	2.1
Value-added time	8.5	0.1	Unnecessary process	0.16	Employee work conditions	8.0	2.8
Traceability	8.1	1.4	Consistency	0.14	Value-added time	8.0	2.8
Competence shift	7.6	2.4	Impact on related processes	0.05	Unnecessary process	8.0	2.8
Unnecessary process	7.4	1.5	Competence match	0.05	Competence match	8.0	2.8
Future proofing	7.1	1.2	Traceability	-	Future proofing	5.5	0.7
Environmental considerations	7.0	2.6	Future proofing	-	Degree of automation	5.5	0.7
Competence match	6.9	1.9	Degree of automation	-	Impact on related processes	5.0	-
Degree of automation	6.6	1.5	Environmental considerations	-	Environmental considerations	1.5	0.7

There seems to be agreement on the lowest ranking factors for the bed logistics and pharmaceutical distribution cases. Thus, *competence match*, *future proofing*, *degree of automation* and *environmental considerations* rank in the bottom five impact factors for pharmaceutical distribution cases. Similarly, these impact factors rank in the bottom five impact factors for the bed logistics cases.

4.4.7 Summary of impact factor comparisons

Across all respondents, the following impact factors are ranked as the top five impact factors: 1) *output quality*, 2) *consistency*, 3) *employee engagement*, 4) *risk of mistakes* and 5) *security of supply*. Similarly, for the Danish cases, *risk of mistakes*, *output quality*, and *employee engagement* are perceived as most important decision criteria. For the US cases, respondents agree that *information management* and *traceability* are among the most important decision criteria, thus differing from the overall ranking of impact factors. In addition, the following three impact factors rank high for US cases: 1) *patient care*, *experience and safety*, 2) *compliance* and 3) *consistency*.

Comparing the US and Danish cases, *risk of mistakes*, *output quality*, and *employee engagement* rank high, which is consistent with the overall ranking. For the bed logistics cases, *output quality*, *employee engagement*, and *consistency* rank high as decision criteria. These criteria are consistent with the overall ranking of decision criteria. In addition, *employee work conditions* and *security of supply* occur for the consolidated ranking where both cases are assigned equal weights. *Security of supply* is also consistent with the overall ranking of impact factors as decision criteria.

For the pharmaceutical distribution cases, *information management*, *security of supply*, *employee engagement,* and *risk of mistakes* rank high as decision criteria. Apart from *information management*, these decision criteria are consistent with the overall ranking of decision criteria across all respondents.

Comparing the bed logistics and pharmaceutical distribution cases, *employee engagement* and *security of supply* reoccur for both process types. In summary, there seems to be some agreement on the most important decision criteria with certain country setting and process specific differences. One of the most notable differences is the perceived high importance of *traceability* for the US pharmaceutical distribution case and the low importance for the Danish case. Overall, the lowest ranking impact factors as decision criteria are *competence shift*, *future proofing*, *competence match*, *degree of automation*, and *environmental considerations*.

All identified impact factors were validated as decision criteria for healthcare logistics processes with the exception of *environmental considerations*, which only seems to apply to the Danish bed logistics case. Furthermore, *degree of automation* ranks low for most cases. In addition, *traceability* and *future proofing* do not seem to be of significance for the Danish pharmaceutical distribution case, although the process could particularly benefit from *traceability* as reported for the US case study. Moreover, the current process for pharmaceutical distribution does not appear to be a viable solution in the long run for the Danish hospital; with future expansions of the hospital and patient safety in mind, *future proofing* should be considered to a larger extent.

Applying all identified impact factors as decision criteria for improving healthcare logistics processes may be an elaborate task if all decision criteria are to be considered. Thus, identifying the most important decision criteria for particular circumstances can help managers identify focus areas for improvement. Furthermore, a smaller number of decision criteria may focus the assessment of possible alternative interventions. Finally, the prioritization of impact factors can help decision makers understand the drivers of change in healthcare logistics.

4.5 APPLYING THE IMPACT FACTORS IN DECISION MAKING

In the following, applications of impact factors are suggested for the decision process of improving healthcare logistics processes. The impact factors can be applied to qualitative and quantitative methods in addition to a combination of the two, i.e. mixed methods. Suggestions for qualitative and quantitative applications are provided in the following. These applications can be applied separately or in parallel for a more nuanced analysis. Meredith and Suresh suggest three types of justification methods: strategic, economic and analytic (Meredith and Suresh, 1986). Strategic methods will be included as a qualitative method, i.e. a descriptive approach. Economic methods are not included, but the suggested analyses are proposed as complementary to an economic analysis. Finally, analytic methods are included as quantitative methods. Another included quantitative approach is the application of impact factors for benchmarking purposes and by association performance measurement.

4.5.1 QUALITATIVE APPLICATION OF IMPACT FACTORS FOR ASSESSMENT

A qualitative application of the impact factors in a decision process could include a description of each of the impact factors for different interventions. In addition, comparing the descriptions of impact factors for different interventions to the strategy of the organization could help align the strategy by selecting a solution that matches the overall strategy and goals of the organization.

4.5.2 QUANTITATIVE APPLICATION OF IMPACT FACTORS FOR ASSESSMENT

P7 illustrates how the impact factors can be used for assessing alternative solutions for a healthcare logistics process by applying the ANP method to the identified impact factors. The application of ANP for assessing alternative solutions is exemplified in P7 by alternative technologies to be implemented in a pharmaceutical distribution process. The ANP method considers the interdependencies between impact factors. A more simplified method is the application of the AHP method or a simple weighted factor model, which do not consider the internal dependencies of impact factors. In any case, it would be worth considering how interventions may affect different aspects of the logistical system.

The impact factors may not only be used for assessing technologies but for assessing the entire process design; i.e. technologies are part of the process design. In broader terms, the impact factors may be used for assessing interventions, i.e. in terms of BPM interventions, logistics and SCM interventions, technological interventions, and organizational interventions. P2 illustrates how impact factors impact the design of processes, e.g. through the implementation of additional quality assuring process steps or interventions which improve the work conditions for employees.

4.5.3 Operationalization of impact factors for benchmarking

The identified impact factors can be operationalized as metrics for benchmarking purposes. P4 elaborates how the impact factors can serve as performance metrics. The performance metrics proposed in P4 relate to 1) quality, 2) security of supply and 3) employee engagement. The quality related measures include *risk of mistakes*, *consistency* and *output quality*. Variability could serve as a measure of *risk of mistakes*. *Consistency* could represent the allowed variability. *Output quality* could refer to the service level provided, e.g. lead time for transports and service level agreements in general. *Security of supply* could be measured as the rate of orders fulfilled by suppliers. Finally, *employee engagement* could be measured as the employee turnover rate and employee absenteeism, e.g. average number of sick days per employee or absence rate. The suggested performance metrics could be used not only for benchmarking purposes but also for pure performance measurement purposes. Furthermore, the identified impact factors can reflect the efficiency and effectiveness aspects of performance.

4.6 Framework for improving healthcare logistics (Part II)

Part I of the framework developed in this thesis was developed in the Literature Review. In this section, Part II of the framework is developed. In the next chapter, the final framework is consolidated and presented.

Based on the results presented up until this point in the Results and in P2, Part II of the final framework proposed in this study is developed. Figure 4.8 illustrates Part II of the framework, which consists of three steps. First, a manager must decide which process to improve. Second, the decision criteria are applied to the subject under investigation, i.e. the process to be improved. As previously described, qualitative/quantitative approaches can be applied to the impact factors for assessing alternative solutions or improvement approaches. These solutions or improvement approaches could be identified based on Part I of the framework and the interventions identified in the case studies. Complementary economic analyses should be conducted to support the decision process. Furthermore, contingent factors should be considered for narrowing down the number of suitable alternatives. Third, based on the quantitative and/or qualitative analyses, managers should be able to select interventions or approaches for improvement.

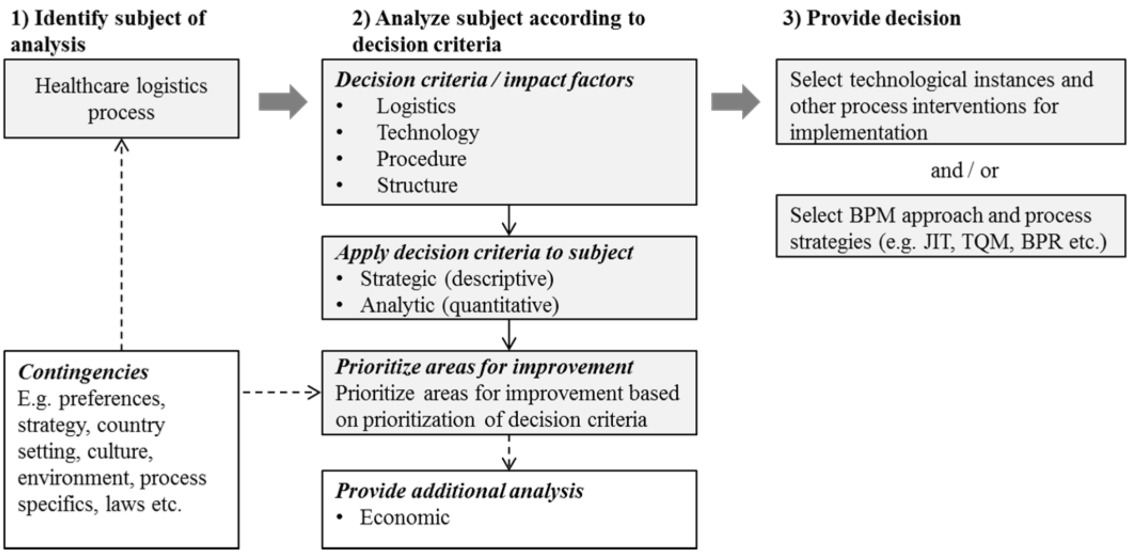

Figure 4.8. Decision framework Part II for improving healthcare logistics processes. Source: P2.

Applying all the identified impact factors as decision criteria in the framework may not be a feasible task in terms of available time and resources. Managers may therefore choose to focus on a number of impact factors, i.e. the impact factors identified as most important. Furthermore, the process subject to improvement may not be the bed logistics or pharmaceutical distribution process, thus managers should look for similarities to these processes in terms of challenges and other process characteristics, e.g. product type, closed or open loop processes, or country setting. Furthermore, the prioritization of impact factor may be different for a particular hospital depending on the type of hospital, environment of operation and the strategy of the organization. A couple of contingent factors were identified in the case studies. First, the use of reorder points mainly applies to tangible items and flows which are not closed-loop. Second, the choice to centralize or decentralize activities may lead to a trade-off between increased lead time and increased transport time as for the bed logistics cases. Third, the choice between centralized and decentralized inventory may depend on the choice of centralization or decentralization of activities. Fourth, applying barcodes or similar technologies may depend on the need and legal requirements to control the process. Fifth, the availability of financial resources is likely to determine whether technologies are implemented. Sixth, the size of the hospital, the need to control the process and the extent of available resources are likely to impact the decision to implement central pharmaceutical inventories in addition to satellite inventories. Seventh, central inventories may be preferable for economic reasons.

4.7 Chapter summary

In this chapter, challenges were identified for each of the case studies. In addition, interventions pertaining to BPM, logistics and SCM, technologies and organizational structure were reported from the case studies and best practices identified. Based on the case study challenges and interventions, factors impacting the decision to improve healthcare logistics processes were identified through coding of the qualitative data. The identified impact factors were then ranked according to importance and compared across cases. Applications of impact factors in a decision process were proposed and Part II of the framework to improve healthcare logistics processes was developed.

5 DEVELOPING THE FINAL FRAMEWORK

In this chapter, the final framework is developed by merging and consolidating Part I and Part II of the framework developed in previous chapters. Furthermore, a guide for how to apply the framework in practice is provided. A summary concludes the chapter.

5.1 CONSOLIDATING THE FRAMEWORK

Interventions for improving healthcare logistics processes were identified in the literature review and results of this study. The interventions of the literature review and the best practices of the case studies are consolidated into the list provided in Table 5.1.

Table 5.1. Identified interventions in literature and case studies

Type	**Intervention**	**Source of identification**	
		Literature	*Case studies*
BPM	BPR	X	
	Cellular operations	X	
	Performance measurement	X	X
	Benchmarking	X	
	Process standardization/SOPs	X	X
	Reduce and control handovers		X
	Use manual processes when necessary	X	X
Logistics and SCM	*Replenishment systems*		
	Replenishment policy/reorder point	X	X
	JIT	X	
	Stockless system	X	
	VMI	X	X
	Single dose system	X	
	Centralization vs. decentralization of activities	X	X
	Centralization vs. decentralization of inventories	X	X
	SC design		
	SC integration	X	
	SC and logistics innovation	X	
	Responsive SCs	X	
Technologies	Automated transport (AGVs, pneumatic tube systems)	X	X
	Automated storage and retrieval (e.g. picking carousel)	X	X
	Barcodes	X	X
	RFID	X	X
	ICTs (including EDI)	X	X
Organization	Continuous Improvement department		X
	Installing sense of pride		X
	Centralization vs. decentralization	X	X
	HRM/education	X	X
	Organizing logistics activities	X	X
	Organizational and social setting	X	

The interventions identified in the case studies are at a more detailed level than the intervention identified in the literature review. To avoid too detailed a summary of interventions for improving healthcare logistics processes, only best practices are included from the case studies. Furthermore, a number of contingent factors were identified for the interventions and can be found in Table 2.7 and 2.8.

In the Literature Review, Part I of the final framework was developed and in the Results, Part II of the framework was developed. The two parts are now merged into a final framework. The final framework consists of six steps and is illustrated in Figure 5.1. The dotted lines indicate optional links between framework elements and will be explained in the following.

In the first step of the framework, decision makers must decide which process to improve. The dotted arrow between the decision criteria/impact factors and the healthcare logistics process in step 1 indicates that impact factors may be used to decide which process to improve, e.g. by identifying major challenges or using weighted impact factors as decision criteria to identify and prioritize areas for improvement. However, other reasoning may be applied at the discretion of the decision maker to select a process for improvement, which is also indicated by the dotted arrow from the "…additional analyses…" box. The arrow between contingent factors and the healthcare logistics process indicates that healthcare logistics processes are embedded in a given context.

In the second step of the framework, decision makers may have identified benefits they wish to achieve or challenges they wish to address. The benefits which can be achieved through different interventions as identified in literature are listed in Table 2.9 in the Literature Review. Similarly, the challenges identified in healthcare logistics literature are found in Table 2.5 in the Literature Review.

Step three of the framework matches benefits with interventions. If the point of departure is the challenges in a process, challenges are first matched with the benefits which can alleviate those challenges. Subsequently, the interventions are identified which can produce those benefits.

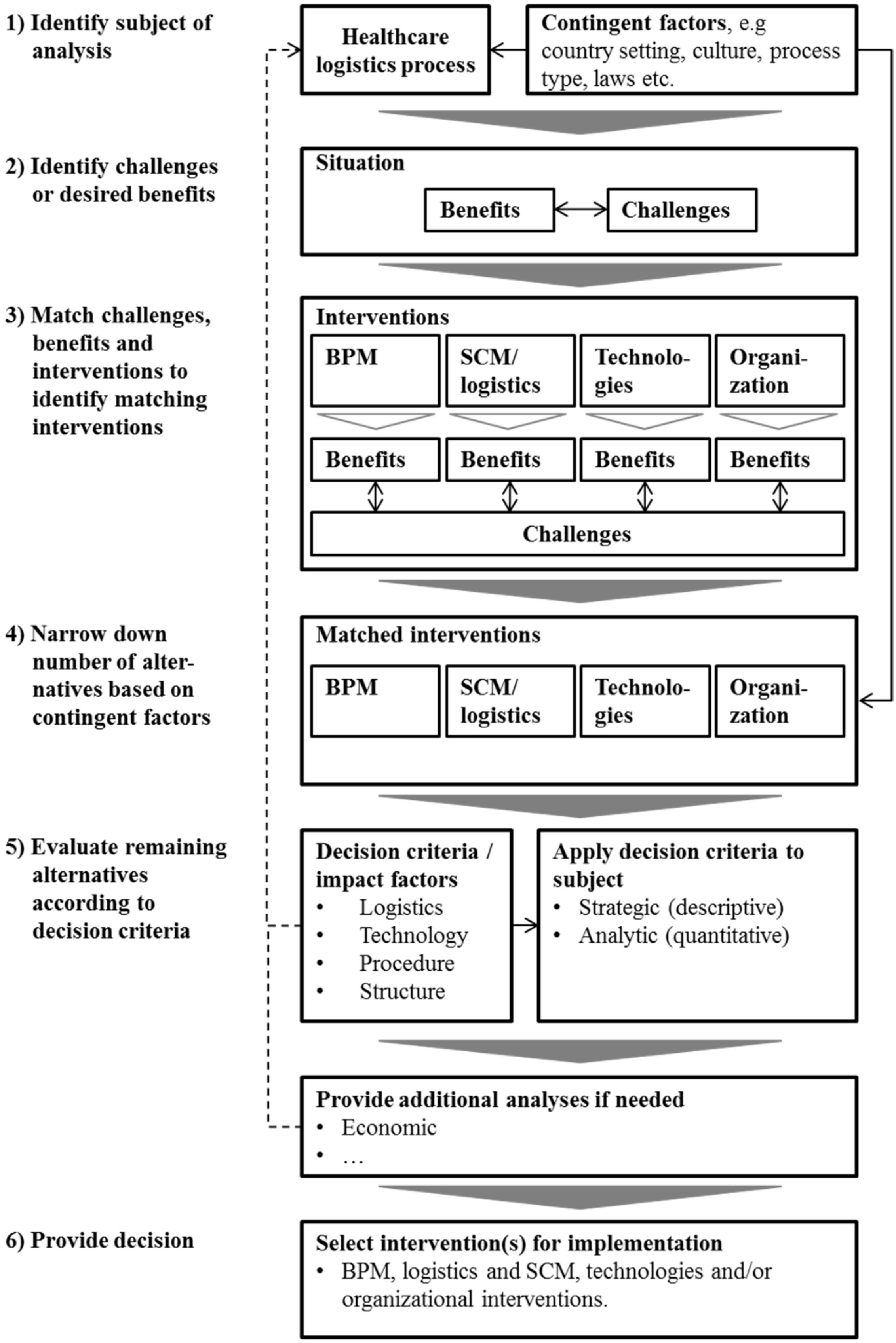

Figure 5.1. Final framework developed for improving healthcare logistics processes

Step four of the framework narrows down the number of interventions from those relevant to achieving certain benefits to those which are relevant under the given circumstances. The contingent factors can relate to process type and country setting, but also the entire list of contingent factors listed in Table 2.7 and 2.8 in the Literature Review. Some interventions which can help provide certain benefits to alleviate a given challenge may not be relevant to that particular problem or situation. The relevance of an intervention must therefore be taken into consideration, e.g. an AGV may not be relevant for the distribution of a service but only for the distribution of tangible items. The application of common sense is therefore an underlying assumption of the framework.

In step five, the remaining alternative interventions are assessed based on the decision criteria identified in this study. The 24 impact factors, which can be used as decision criteria, can be applied to the healthcare logistics process using a quantitative or qualitative approach or both. In a quantitative approach, methods such as AHP, ANP or a weighted factor method could be applied. The quantitative assessment can be based on the decision makers' own prioritization of impact factors or on the prioritizations found in this study. For a qualitative approach, each impact factor could be described and compared for each remaining alternative intervention. Additional analyses such as an economic justification may be necessary.

All or the most important impact factors may be considered in the fifth step of the framework. The prioritization of impact factors in the Results can help determine the most important impact factors, e.g. given the type of process and national context. However, other impact factors may be of greater importance to a particular hospital depending on the specific context. Decision makers therefore need to decide which impact factors they wish to consider.

In the sixth and final step, one or more interventions are chosen for implementation based on the previous steps of the framework.

5.2 CHAPTER SUMMARY

In this chapter, the two parts of the framework developed in previous chapters were merged and consolidated into one final framework. The final framework consists of six steps to improve healthcare logistics processes. The identified interventions, contingent factors and impact factors are inherent to the framework.

6 DISCUSSION AND LIMITATIONS

In this chapter, each of the research questions is answered and discussed in relation to extant literature. The meta-RQ is answered through the composite RQs, which in turn are answered through the underlying SQs. Furthermore, the limitations of the study are presented, followed by a summary of the chapter.

6.1 DISCUSSING RQ 1 | PROCESS CHARACTERIZATION

The first research question is discussed in this section and is formulated as follows: *"How can healthcare logistics processes be characterized in terms of challenges and composite design elements?"* The research question consists of four sub-questions, each of which will be discussed to answer RQ1.

6.1.1 ANSWERING SQ 1.1 | CHALLENGES

What are the challenges specific to healthcare logistics processes? The case studies and literature review revealed a number of challenges inherent to healthcare logistics. Table 2.5 in the Literature Review lists a set of challenges specific to healthcare logistics processes. Some of the identified challenges are specific to certain process types. Thus, for pharmaceutical products and blood products, challenges include product availability, perishability and product waste, special handling of items, and process interruptions. In addition, the literature review provides a list of challenges applicable to healthcare logistics processes in general; the most significant challenges include systems integration, ensuring the right skills, overstocking, balancing quality and costs, inventory shrinkage, lack of SC integration, complexity in the SC, unpredictability, delays, process immaturity, inefficient processes, political agendas, and high SC costs. Towill argues that from a logistics perspective, the major reason for the esteemed Kaiser Permanente's superiority is their understanding of designing and delivering healthcare systems that carefully balance cost, queueing time, quality and consistency (Towill, 2006).

Challenges similar to those identified in the Literature Review were identified in the case studies. However, unpredictability, political agenda and high SC costs were not mentioned as particular challenges in the case studies. Although high SC costs were not perceived as particular issues, SC costs were indirectly considered an issue particularly for the Danish hospitals due to budgetary limitations. It is worth mentioning that unpredictability and variability in the healthcare SC often are a product of both natural and artificial variability in the SC. Variability in healthcare occurs due to three factors: 1) clinical variability, 2) flow variability, and 3) professional variability (Litvak and Long, 2000). Unscheduled demand in healthcare is subject to natural variation, whereas scheduled demand may be subject to artificial variation caused by poor hospital practices. Studies show that unscheduled demand can be equally or more predictable than scheduled demand (Litvak et al., 2005; Walley et al., 2006). To cope with natural variability, the level of predictability for unscheduled demand allows for forecasting and planning of resources to some extent, thereby improving resource utilization. To cope with artificial variation as a result of poor hospital practices, these practices can be eliminated (Litvak et al., 2005; Walley et al., 2006). It is therefore important to identify the source of variation (Walley et al., 2006).

The Results and P3 report how the case studies revealed challenges such as SOP adherence, work conditions, employee retention and absenteeism, physical constraints of the hospital, the possible negative impacts of a process on related processes, communication challenges, collaboration with other staff groups, continuous education, excessive use of water, balancing priorities, locating people and items, control of the process, stock count accuracy, and maintenance of central and decentral technologies. As reiterated by Towill and Christopher, it is important to adopt a holistic approach to improvement to avoid sub-optimization (Towill and Christopher, 2005). They reflect on Braess' Paradox which states that optimizing one small part of a system may have a negative impact on the system as a whole. It is therefore important to consider the *impact on related processes*.

In a survey on global health supply chain issues, Privett and Gonzalves identify the top ten issues as perceived by practitioners (Privett and Gonsalvez, 2014). Two issues relevant to supply chain agents situated upstream from the hospital were identified, i.e. shipment visibility and warehouse management. Eight of the identified challenges are relevant to hospital logistics: 1) lack of coordination, 2) inventory management, 3) absent demand information, 4) human resource dependency, 5) order management, 6) stock-outs, 7) expiration of items, and 8) temperature control. These challenges are rather broadly formulated and mainly occurred for the pharmaceutical distribution cases. However, not all of the challenges identified by Privett and Gonzalves were necessarily expressed as an explicit challenge in the case studies. Lack of coordination, inventory management, absent demand information, human resource dependency and stock-outs were identified as challenges in the cases in some form. However, order management, expiration of items and temperature control, although occurring in the pharmaceutical cases, were not perceived as explicit challenges.

6.1.2 Answering SQ 1.2 | Interventions

Which interventions can hospitals implement to improve healthcare logistics processes? Interventions for improving healthcare logistics processes were identified in the literature review provided in P1 and in the case studies as reported in the Results. The identified interventions can be divided into four categories representing changes to processes, logistics and SCM aspects, technologies and organizational aspects. The interventions can be perceived as elements of logistics processes in hospitals and can contribute to characterizing those processes. Thus, the process interventions describe aspects of the process design. Furthermore, the investigated process types carry out logistics activities. Finally, technologies and staff resources perform the logistics activities. Each type of intervention is discussed in the following.

BPM interventions. Some authors argue that a process approach is difficult to adopt in a healthcare settings due to the complex environment and demand uncertainty (Aronsson et al., 2011; Lillrank et al., 2011). However, the literature review showed that BPM approaches have been successfully applied in a healthcare logistics setting, including BPR, cellular operations, performance measurement, benchmarking, and process standardization. In addition, the case studies included best practices such as reducing and controlling handovers to ensure control of the process and to reduce the risk of mistakes. Moreover, P4 suggests how healthcare logistics processes could be benchmarked by operationalizing the identified impact factors. Another similarity between literature and case studies is the continuous improvement approach characteristic to the US hospital. Similarly, lean projects were carried out in the Danish hospitals, although not for the investigated processes in particular. Thus process improvement approaches applicable in a healthcare setting may likely apply to healthcare logistics. One example is the application of lean in healthcare (Souza, 2009), although lean in healthcare tends to focus on the tools and techniques of lean rather than a system-wide implementation (Radnor et al., 2006, 2012). This finding by Radnor et al. is consistent with the findings of the literature review in P1, which only reported how JIT had been implemented in healthcare logistics and not lean as a management philosophy. Furthermore, as complementary to lean, some authors argue for an agile or leagile approach to cope with variability in a healthcare setting, e.g. (Rahimnia and Moghadasian, 2010).

Lean and other management philosophies adopt a quality approach. Another quality approach is TQM, which studies have shown is applicable in a healthcare setting, e.g. (Smith and Offodile, 2008; Xiong et al., 2015). An alternative quality related approach applicable in a healthcare setting is six sigma (Taner et al., 2007), although a survey of patient logistics in Dutch hospitals shows that six sigma is one of the least implemented improvement approaches (van Lent et al., 2012). Furthermore, as suggested in P4, achieving a six sigma quality level may prove difficult for healthcare logistics processes due to the nature and frequency of the processes.

Logistics and SCM interventions. The logistics interventions identified in the literature review relate to either replenishment systems or SC design. Interventions related to replenishment systems include replenishment policy, JIT, stockless system, VMI, and a single dose system. Interventions related to SC design include SC integration, SC and logistics innovation, and responsive SCs. For the case studies, the replenishment policy was represented through the use of reorder points. Furthermore, decentralization and centralization of both activities and inventories were significant differences identified between the case studies.

Closely related to inventories is the concept of decoupling points (Rahimnia and Moghadasian, 2010). Towill and Christopher (2005) consider the decoupling points for patient flows. These decoupling points can ensure that different pipelines of healthcare delivery do not interfere with each other, thereby avoiding disruptions (Towill and Christopher, 2005). Similarly, decoupling points may be worth taking into consideration for healthcare logistics.

Aronsson et al. (2011) found that for patient flows, it is not possible to be lean before the decoupling point and agile after the decoupling point. They adopt a slightly different approach to lean and agile SCs, arguing that the healthcare SC in the case of patient flows should be divided into sub-processes according to department boundaries. Characteristics of each process such as variability and volume should then determine whether a given sub-process should be agile or lean. Furthermore, the authors argue that the difference between lean and agile operations lies in the variability of lead times and capacity. Thus, a lean approach operates with fixed, i.e. planned, capacity and aims for high utilization of resources. This leads to variability in lead times, i.e. waiting times, if demand fluctuates. An agile approach, however, operates with fixed lead times and flexible capacity, requiring high availability of extra resources (Aronsson et al., 2011).

Modig and Åhlström (2013) discuss the concept of efficiency in relation to lean and distinguish between resource efficiency and flow efficiency. Resource efficiency focuses on the utilization of resources and maximizes value-added time for the resource. Flow efficiency focuses on the flow of a unit and maximizes value-added time experienced by the unit. Lean is perceived as a strategy striving for increased resource efficiency and flow efficiency within the natural limitations caused by variation (Modig and Åhlström, 2013). Modig and Åhlström argue that *This is lean*. However, this view of lean seems to be in contrast with the view by Aronsson et al. (2011) who argue that lean aims for fixed capacity and high resource utilization, thus supporting the point by Modig and Åhlström (2013) that several definitions and perceptions exist of what lean is.

In relation to SC design, designing a responsive SC was identified as an intervention in literature. Callender and Grasman argue that a responsive SC might be better than an efficient cost-focused SC. However, a responsive SC does not necessarily imply high inventory levels. Their study found that one third of healthcare providers experienced frequent emergency orders because of stock outs (Callender and Grasman, 2010). Responsiveness was not a particular issue in the case studies.

In addition to the logistics and SCM interventions identified in literature, healthcare logistics processes might benefit from practices found in the manufacturing industry. SC models adopted from manufacturing may have to adapt to a service environment such as healthcare. However, Aitken et al. argue that both manufacturing and service industries struggle to achieve seamless supply chains and that there are more similarities than dissimilarities between service and manufacturing from an SCM perspective (Aitken et al., 2016).

Technological interventions. The applied technologies identified in healthcare logistics literature include automated transport, e.g. AGVs and pneumatic tubes, automated storage and retrieval, barcodes, RFID, and ICTs in general. Similar technologies were identified in the case studies in addition to washing machines and equipment to load and unload mattresses. However, other technologies could apply in a healthcare logistics setting, i.e. in industries at the forefront of automation such as manufacturing. As an example, iBeacons were suggested by an interviewee at the primary case hospital to prompt relevant information to cleaning staff when entering a room (see P3 and P6).

Organizational interventions. The types of organizational interventions identified in literature include organizing logistics activities, i.e. determining which departments carry out logistics activities, HRM, centralization vs. decentralization, and organizational and social setting. In terms of organizing logistics activities, these activities were carried out by logistics departments in the case study hospitals. Furthermore, the hospital wide introduction of a Continuous Improvement department provided a continuous improvement culture and platform for improvement activities in the US hospital. In relation to HRM, installing a sense of pride and ensuring staff education were examples identified in the case studies. The centralization vs. decentralization aspect was also identified in the case studies; the organizational structure of logistics activities was mainly centralized, although inventories and activities could be centralized or decentralized.

Yasin and colleagues conducted a survey of hospitals in Tennessee investigating the implementation and success of managerial tools and techniques for healthcare improvement (Yasin et al., 2002). The study found that BPR, JIT, job reengineering, and organizational restructuring were the least implemented managerial philosophies in the surveyed hospitals. The most implemented improvement philosophies were TQM, continuous improvement and benchmarking. For-profit hospitals reported more success with implementing TQM, BPR and job reengineering than non-profit hospitals, whereas non-profit hospitals had experienced more success with organizational restructuring than for-profit hospitals. Both hospital types showed more similar success rates for benchmarking, continuous improvement and JIT. These findings show that different types of improvement philosophies are applicable in a healthcare setting. Of the investigated managerial philosophies, job reengineering was the only technique not identified in this study. Another interesting finding of the study is that the success of the implementation depends on the context and contingencies of the hospital. Similarly, the studies conducted for this thesis were carried out for different country settings and process types.

6.1.3 Answering SQ 1.3 | Benefits of interventions

Which benefits can be identified for interventions and approaches for improving healthcare logistics processes? The literature review and the results of the study identified benefits for each intervention. In the literature review, the following nine types of benefits were identified: 1) process performance and cost savings, 2) quality, 3) inventory management, 4) flow management, 5) patient care, 6) compliance, 7) staff, 8) procurement, and 9) information management and SC coordination. The benefits identified in the case studies were identified along with reasons for implementing interventions. Thus, the benefits relate to the impact factors identified in this study, which in turn relate to logistics, technologies, processes and organizational structure. Out of the 24 identified impact factors, the identified benefits relate to all but two impact factors, namely *downtime and maintenance* and *utilization of technologies*. In addition, the benefits identified in the case studies would improve overall performance of logistics processes in terms of efficiency and effectiveness. As noted in the Introduction, cost containment and high quality care are major concerns within healthcare (OECD, 2015; Saltman and Figueras, 1997; WHO, 2010). Quality is reflected in the benefits identified both in the literature review and the benefits identified in the case studies. Furthermore, the benefits identified in the Literature Review and the Results relate to costs in terms of efficient utilization of resources. Moreover, all the hospitals would provide economic justification for any potential investments in interventions.

6.1.4 Answering SQ 1.4 | Contingent factors

What are the contingent factors that determine when different interventions and approaches for improving healthcare logistics processes are recommendable? Whether an intervention should be implemented depends on a number of contingent factors. The literature review in P1 identified 20 contingent factors relating to logistics and SCM interventions and 13 contingent factors relating to technological interventions. The following seven contingent factors were identified in the case studies:

1) Reorder points mainly applies to tangible items and not closed-loop flows.
2) Trade-offs exist in terms of transport and lead time for the centralization or decentralization of activities.
3) Centralization vs. decentralization of inventories depends on centralization/decentralization of activities.
4) Legal requirement and process control may provide incentives for implementing interventions.
5) The implementation of interventions depends on available financial resources.
6) Hospital size, the need to control processes, and the extent of available resources influence the decision to centralize or decentralize activities.

7) Central inventories may be preferable for economic reasons.

Comparing the contingent factors identified in the case studies and literature review, financial resources identified as a contingent factor in the case studies is reflected as the contingent factor TCO in the literature review (Gebicki et al., 2014; Marino, 1998; Pinna et al., 2015). TCO was identified as a contingent factor related to logistics and SCM interventions, but could apply to any type of intervention. Finally, tangibility was identified in the studies as a contingent factor related to reorder points and was identified in the literature review as a contingent factor for implementing a JIT solution (Whitson, 1997).

6.1.5 Answering RQ1 | process characterization

How can healthcare logistics processes be characterized in terms of challenges and composite design elements? Pan and Pokharel provide a framework for characterizing logistics activities in hospitals to enable the design of a better system delivering more efficient care services. The framework contains four aspects: 1) hospital profile, 2) inventory management, 3) motivators and barriers to ICT use, and 4) alliances and outsourcing (Pan and Pokharel, 2007). Similarly, a study of French and US hospitals compares characteristics based on 1) the extent of responsibility given to logistics departments, 2) the manner of distribution of supplies, 3) the amount or volume of pharmaceuticals distributed, 4) degree of partnerships between hospitals and suppliers, and 5) the past and future efforts of improving the logistics function (Aptel and Pourjalali, 2001).

In this study, healthcare logistics processes are characterized in terms of challenges and the constituent elements, i.e. process steps, logistics and SCM aspects, implemented technologies, and organizational structure. Comparing the characterization in this study to that conducted by Pan and Pokharel (2007), *inventory management* relates to *logistics and SCM*; *motivators and barriers to ICT use* relates to *implemented technologies*; and *alliances and outsourcing* relates to *organizational structure*. The two approaches differ with respect to including the hospital profile and process steps. Furthermore, the benefits of interventions and contingent factors for interventions were identified in this study. Benefits of interventions identified in the literature review can be divided into nine different types of benefits. In addition, benefits of interventions identified in the case studies relate to the impact factors identified in this study except for *downtime and maintenance* and *utilization of technologies.* The contingent factors identified in literature have only been identified for logistics/SCM and technological interventions. Moreover, seven contingent factors were identified in the case studies.

Comparing the characterization in this study with that of Aptel and Pourjalali (2001), the extent of responsibility given to logistics departments, the manner of distribution of supplies, and the past efforts of improving the logistics function were also described in this study. However, amounts or volumes and the degree of partnerships between hospitals and suppliers were considered to a lesser extent.

6.2 Discussing RQ2 | Impact factors

The second RQ considered in this study is: *"Which factors should decision makers consider when improving healthcare logistics processes?"* This RQ is answered through two underlying SQs, which will be discussed in the following.

6.2.1 Answering SQ 2.1 | Identifying impact factors

Which factors impact the design of healthcare logistics processes? Based on the case studies, 24 impact factors were identified. P2, P3 and P4 together with the Results show how the impact factors were identified. However, the impact factors do not apply to all types of healthcare logistics processes. *Environmental considerations* was only found relevant for the Danish bed logistics case study. Furthermore, additional impact factors identified in the US case studies were not validated for the Danish cases, although they seem applicable to a Danish setting.

The impact factors were identified based on challenges and reasons for implementing interventions in the case studies. Additional challenges and interventions were identified in the literature review. Some challenges and interventions were identified in both the case studies and the literature review, whereas others were only identified in one or the other. The challenges only identified in the literature review include 1) lack of predictability, 2) political agendas and 3) high SC costs. The types of interventions only identified in the literature review include *responsive SCs*, i.e. a logistics and SCM intervention, and *organizational and social setting*, i.e. an organizational intervention. Two benefits were identified in literature which had not been identified in the case studies. These two benefits relate to *procurement* and *information management and SC coordination*. Based on the challenges, interventions and benefits of interventions identified in literature, the following impact factors could be added to the developed framework:

- Responsiveness
- SC coordination
- Procurement

- Social considerations
- Political agendas
- Lack of predictability
- Costs

Costs were deliberately not included as part of the framework as the framework is meant as complementary to an economic analysis. Furthermore, 15 decision criteria were identified in the literature review for selecting technologies. In addition to the impact factors identified in the case studies and the possible additional impact factors identified above, the following impact factors could be added for technologies in particular:

- Reductions in theft and wasted products
- Improved reverse logistics
- Improved information storage
- Improved CPFR

Some of the possible additional impact factors identified in the literature review relate to the healthcare supply chain in a broader scope than the focus of this thesis. Depending on the scope of the decision to be made, these impact factors may or may not be included in the decision process of improving healthcare logistics.

6.2.2 ANSWERING SQ 2.2 | IMPACT FACTORS AND PROCESS DESIGN

How do impact factors affect the design of healthcare logistics processes? The design of healthcare logistics processes is to be understood as the combination of composite elements of a process pertaining to process steps, technologies, logistics and SCM aspects, and organizational structure. P2 shows how interventions had been implemented in the bed logistics process in Danish hospitals due to particular focus areas or impact factors. E.g. additional process steps had been introduced to improve the *output quality* of a process. In some hospitals, washing machines had been introduced to increase the cleanliness of beds, i.e. the *output quality*. P4 also provides examples of interventions according to impact factors. E.g. the US hospital had implemented a 7-step cleaning process to ensure *consistency*, reduce the *risk of mistakes*, improve *output quality*, and ensure *competence match*.

Some impact factors are perceived as more important than others depending on the process. Comparing the Danish and US cases, *environmental considerations* was only deemed relevant for the Danish bed logistics case. Thus, some hospitals had implemented washing machines because of their low water usage.

In P5, relations between impact factors were suggested based on the Danish bed logistics case study. These relations are important to consider when making changes in a healthcare logistics system. One of the identified relations between impact factors is the effect of *competence match* on *output quality*. Similarly, *competence shifts* impact the quality related factors *risk of mistakes* and *consistency*. P2 and the Results show how *competence match* and *competence shifts* affect quality, indicating that these impact factors should receive more attention than suggested by the low rankings as decision criteria.

Although less automated than its US counterparts, the Danish bed logistics case study ranked *degree of automation* higher than the US case studies. However, the case studies showed that automation is not a goal in itself and that a semi-automated solution may be preferable due to staff considerations, space availability and flexibility. In some cases, a manual process may even be preferable, e.g. in the case of patient transport.

The Results outline differences in perceived importance of impact factors. The five highest ranking impact factors are 1) *output quality*, 2) *consistency*, 3) *employee engagement*, 4) *risk of mistakes* and 5) *security of supply*. For Danish cases, *risk of mistakes*, *output quality*, and *employee engagement* are high ranking impact factors. For the US cases, 1) *patient care*, *experience and safety*, 2) *compliance* and 3) *consistency* also rank high. In addition, *information management* and *traceability* rank high for US cases, which is different from the overall ranking. For the bed logistics cases, *output quality*, *employee engagement*, and *consistency* are perceived of high importance. For the pharmaceutical distribution cases, *information management*, *security of supply*, *employee engagement* and *risk of mistakes* rank high as decision criteria. Interestingly, *traceability* ranks high for the US pharmaceutical distribution case and low for the Danish pharmaceutical distribution case. The lowest ranking impact factors are *competence shift*, *future proofing*, *competence match*, *degree of automation*, and *environmental considerations*. These differences in the importance of impact factors should be considered when assessing potential changes to healthcare logistics processes. The differences suggest that contingencies, e.g. country setting and process type, determine what is considered important for improving a process and consequently influences the preferred design of a healthcare logistics process.

The quality and cost aspects of healthcare motivating this study are reflected in the impact factors. Thus, the impact factors *output quality*, *risk of mistakes* and *consistency* all relate to quality (see P2 and P4). Other aspects of quality include *lead time* and *security of supply*. Furthermore, impact factors such as *competence shifts*, *competence match* and *employee engagement* affect the quality of provided services (P2, P4 and P5). Regarding costs, the efficiency related impact factors all contribute to a better use of resources, thereby promoting cost containment. In addition, the decision criteria *lead time*, *value-added time*, *risk of mistakes*, and *output quality* can also be viewed from a cost perspective. Moreover, *degree of automation* and the elimination of *unnecessary processes* can increase process efficiency. Using the proposed framework as a decision tool to change healthcare logistics processes will therefore promote processes that are more cost effective and quality oriented.

6.2.3 ANSWERING RQ2 | IMPACT FACTORS

Which factors should decision makers consider when improving healthcare logistics processes? A set of 24 impact factors were identified in the case studies for improving healthcare logistics processes. In addition, seven impact factors could be added based on the discussion of literature. Moreover, four impact factors could be added as impact factors for technologies in particular based on the discussion of literature. The impact factors were shown to impact the design elements of healthcare logistics processes, i.e. process steps, logistics and SCM aspects, technologies, and organizational structure. Differences in the importance of impact factors were identified for national settings and process types. Furthermore, the interrelations between impact factors should be considered when considering changes to a healthcare logistics system.

6.3 DISCUSSING RQ3 | ASSESSMENT

The third RQ considers the assessment of potential solutions for healthcare logistics processes and is framed as follows: "*How can the identified impact factors be used to assess healthcare logistics systems?*" This RQ is answered based on two sub-questions, each of which will be discussed in the following.

6.3.1 ANSWERING SQ3.1 | BENCHMARKING AND PERFORMANCE MEASUREMENT

How can the identified impact factors be used to measure and benchmark the performance of healthcare logistics processes? Bourne et al. propose that the design of performance measurement systems can be divided into three main phases: 1) the design of performance measures, 2) the implementation of the performance measures, and 3) the use of performance measures (Bourne et al., 2000). In relation to the design of performance measures, P3 and P6 suggest a set of performance measures for the hospital cleaning process in a Danish hospital. Furthermore, P4 suggested a set of performance measures based on the impact factors for the purpose of benchmarking. In terms of implementing performance measures, P3 and P6 suggest how the identified impact factors can be used for assessing technologies which enable data capturing and performance measurement. This assessment is part of the implementation phase proposed by Bourne et al. in which data collection is enabled to produce regular performance measurements. The final stage of designing a performance measurement system, i.e. the use of performance measures, has not been treated in this study.

The performance measures proposed in P4 were developed based on the highest ranking impact factors. These performance measures relate to *quality*, *security of supply* and *employee engagement*. The performance measure proposed in P3 and P6 relate to *quality*, *employee engagement, customer satisfaction* and *lead time*. However, identifying the performance metrics was not the main purpose of this paper. Instead, P6 focuses on how data could be captured and performance metrics implemented.

Although benchmarking and performance management both consist of performance metrics, the two concepts are distinctly different from each other. Performance measurement can be defined as *"the process of quantifying the efficiency and effectiveness of action"* (Neely et al., 2005). Accordingly, each of the impact factors have been divided into efficiency and effectiveness related factors to reflect these performance aspects. Furthermore, the performance metrics developed in P3 and P4 relate to improved service, quality and cost containment, which were the initial motivators of this study. Thus, the developed quality metrics relate to both output quality, e.g. a clean bed, as well as the timely delivery of a service, e.g. *lead time* for transports and *cycle time* for cleaning. Finally, the cost aspect is represented through the efficiency aspect of performance measurement, i.e. the economic use of resources.

Performance is multi-dimensional and multiple performance measures are therefore necessary to reflect performance (Chow et al., 1994). Chow et al. argue that logistics performance should reflect a set of goals and provide examples of such goals. Those also considered in the case studies include job security and working conditions, customer satisfaction, product availability, cost-efficiency, social responsibility, on-time delivery, keeping promises, and low loss and damage (Chow et al., 1994). Korpela and Tuominen use the factors *reliability*, *flexibility*, *lead time*, *cost-effectiveness* and *value-added* for the purpose of benchmarking logistics operations (Korpela and Tuominen, 1996). Each of these performance aspects are considered in this study. *Flexibility* was mentioned in both papers (Chow et al., 1994; Korpela and Tuominen, 1996), but is only considered to a limited extent in this research project.

Wong and Wong define benchmarking as a management tool which systematically searches for best practices, innovative ideas and efficiencies for continuous improvement purposes (Wong and Wong, 2008). In addition, benchmarking consists of both a best practice aspect and a performance metrics aspect (Camp, 1989; Voss et al., 1997). Some best practices were identified in the thesis Literature Review, in the literature review in P1, and in the Results. However, best practices may also differ according to the circumstances under which a hospital operates; i.e. best practices for one type of hospital may not be best practice for another type of hospital. Thus, the framework developed in this study can serve as a decision tool for determining the most suitable solution given the circumstances of a hospital. The identified best practices should therefore be considered a catalog from which possible interventions can be assessed for possible implementation.

Some of the challenges related to benchmarking healthcare logistics SCs have been addressed in P4. The quantification of impact factors according to the importance for improving healthcare logistics processes addresses the issue of differences in importance of performance measure across organizations (Simatupang and Sridharan, 2004), country borders (van Lent et al., 2010), and contexts (Sousa and Voss, 2001, 2008). Moreover, the framework developed in this study takes these differences into account by allowing decision makers to prioritize each aspect of the framework in the decision process.

The benchmarking method developed in P4 proposes a method for benchmarking healthcare logistics processes across hospitals. However, benchmarking healthcare logistics processes against logistics processes in other industries, e.g. manufacturing, might provide useful insights for improvement potential. Camp distinguishes between four different types of benchmarking (Camp, 1995):

1) Internal

2) Competitive
3) Functional
4) Generic

Internal benchmarking provides the least potential whereas generic process benchmarking, i.e. regardless of process type and industry, provides the highest potential, but is difficult in practice. Looking outside the healthcare industry could therefor provide useful learning points for healthcare logistics managers.

In addition to using the impact factors as performance metrics, the impact factors could be applied as a type of Balanced Scorecard. In the Balanced Scorecard, the *financial*, *customer*, *internal business process* and *innovation and learning* perspectives are balanced (Kaplan and Norton, 1992). Furthermore, Brewer and Speh developed an SCM Balanced Scorecard consisting of *end customer benefits*, *SCM goals*, *SCM improvement* and *financial benefits* (Brewer and Speh, 2000). Moreover, Radnor and Lovell justify the use of the Balanced Scorecard for a UK healthcare setting (Radnor and Lovell, 2003). The perspectives of the framework developed in this study are not similar to those of a Balanced Scorecard as the framework considers the perspectives Logistics, Technology, Procedure and Structure. However, these four aspects including their underlying impact factors should be balanced according to the prioritization of impact factors. One way to balance the Logistics, Technology, Procedure and Structure perspectives is by applying quantitative methods such as ANP and AHP to assess different solutions. Applying the impact factors as part of an assessment tool is discussed in the following section.

6.3.2 Answering SQ3.2 | Fit of solution

How can healthcare logistics processes be assessed to ensure a solution that best fits the preferences of a hospital? Hospitals often do not achieve the expected goals from logistics and SCM interventions in healthcare, and managers must therefore often rely on their own experiences and judgment for selecting an improvement approach (van Lent et al., 2012; Romero and Lefebvre, 2015; Volland et al., 2016). The framework developed in this study allows for an assessment of the intervention most suitable for the needs and preferences of a hospital. The framework consists of six steps and allows for a qualitative and/or quantitative assessment of alternative interventions. The framework provides limited guidance as to selecting which process to improve, although the framework may focus the attention to areas for improvement, e.g. by identifying major challenges or through the prioritization of impact factors. Others have provided more guidance on selecting processes for improvement, e.g. (Davenport, 1993; Hammer and Champy, 1993).

The catalog of practices identified in the literature and in the case studies provides a list of interventions for potential assessment. The developed framework narrows down the possible alternatives, at first based on the contingent factors, and subsequently based on the application of the impact factors to find the most suitable solution according to the hospital's needs and preferences. The use of multiple decision criteria methods allows for the assessment of solutions by simultaneously considering different aspects of the solution. The importance of these aspects may differ across hospitals depending on the environment in which they operate, the strategy of the hospital, and other contingent factors.

ANP is one method for prioritizing different alternatives based on a comparison of decision criteria in relation to these alternatives. P7 applies the ANP method to the identified impact factors to assess and prioritize three alternative solutions for the pharmaceutical distribution process. Applying the ANP method allows for a quantitative assessment of solutions whilst taking the interdependencies between decision criteria into account (Saaty, 2004a). A more simple method would be the application of the AHP method and an even simpler method would be the weighted factor model (Meredith and Suresh, 1986). Similar applications include Korpela and Tuominen who benchmark logistics operations by applying the AHP method to a set of critical success factors (Korpela and Tuominen, 1996). Alternatives or complementary approaches to an analytic method are economic or strategic justification, i.e. descriptive (Meredith and Suresh, 1986). Providing a qualitative or descriptive account of each of the impact factors in relation to alternative solutions could provide more nuances and enhance the analysis.

A particular aspect of assessing alternative solutions is the assessment of technologies. In P2, technologies are assessed as part of a process design rather than in isolation. In P3 and P6, track and trace technologies are assessed in terms of their ability to capture and provide valid data. Factors putting data validity at risk were thus identified as factors impacting the selection of a suitable technology. The purpose of technology assessment methods is to inform policy makers about the impact of a new technology. Health technology assessment in particular informs policy makers about technologies that solve a health problem and improve the quality of life (Ritrovato et al., 2015; WHO, 2015). The purpose of assessing technologies in this study is therefore more aligned with technology justification, e.g. (Meredith and Suresh, 1986).

6.3.3 Answering RQ3 | Assessment

The impact factors identified in this study can be used for performance measurement and benchmarking purposes. The quantitative ranking of impact factors enables the identification of the most important impact factors and hence the most suitable aspects to be considered in performance measurement and benchmarking. The other assessment aspect in which the impact factors can be applied is the assessment of alternative interventions in healthcare logistics. A framework was developed for assessing alternative solutions using multiple decision criteria methods. The context of a hospital, and subsequently the ranking of the impact factors, enables the selection of an intervention which reflects the needs and preferences of the hospital.

6.4 Discussing the meta-RQ

How can hospitals improve their logistical processes to ensure that the process design and performance fit the needs and preferences of a hospital? According to Böhme and colleagues, literature provides little guidance on which intervention will be most effective for a given situation (Böhme et al., 2016). The interventions identified in the literature review and case studies may only be applicable under certain circumstances and provide the best results under particular conditions. Contingency theory states that contingent factors determine the success and impact on performance of implementing best practices (Sousa and Voss, 2008). The theory assumes that the context determines which OM practice or intervention should be implemented. In a way, contingency theory restricts the practices that can be chosen. Sousa and Voss (2008) distinguish between three types of variables in contingency theory: 1) contextual variables, 2) response variables and 3) performance variables.

Contextual variables can be divided into four types of variables: national context/culture, firm size, strategic context, and other organizational context variables. The contextual variables are usually exogenous and cannot be controlled or only to a limited extent (Sousa and Voss, 2008). The “needs and preferences” as expressed in the meta-RQ are determined by the contextual variables. I.e. ensuring a solution that fits the “needs and preferences” of a hospital corresponds to the best fit between the contextual variables and response variables according to the performance variables. For this study, the national context is Denmark and the US, and the hospital size differs between medium sized and large hospitals, e.g. according to the classification of hospital size by Yasin and colleagues (2002): small hospitals (0-100 beds), medium sized hospitals (101-499 beds) and large hospitals (500+ beds). A strategic context could in the hospital cases represent the difference between public and private hospitals. In this case the private hospital is a non-profit hospital. Furthermore, in an OM setting, process type is considered a contextual variable (Sousa and Voss, 2008), e.g. bed logistics, hospital cleaning and pharmaceutical distribution. The contingency factors identified in this study correspond to a type of contextual variable in the contingency theory terminology (Sousa and Voss, 2008).

The response variables are the organizational or managerial activities undertaken in response to the context variables (Sousa and Voss, 2008). In the case studies, the response variables correspond to the identified interventions, i.e. BPM interventions, logistics and SCM interventions, technological interventions, and organizational interventions.

The last type of variable in contingency theory is the performance variable. Performance variables explain the selection of interventions or OM practices by evaluating the fit between contextual variables and response variables (Sousa and Voss, 2008). Thus, the performance variables of contingency theory correspond to the impact factors identified in this study. Some impact factors, i.e. performance variables, were only found to be relevant for certain process types and national contexts. Furthermore, differences in perceived importance of the impact factors were identified in the case studies. These perceived differences in the importance of impact factors suggest different foci of the hospitals depending on the context, e.g. country setting and process type. These differences in perceived importance fit well with the underlying assumptions of contingency theory, i.e. that the success of practices or interventions is context dependent.

This study advocates a systems approach for selecting practices or interventions to be implemented. In a systems approach, all contingencies, response variables and performance variables must be considered simultaneously when selecting practices or interventions to be implemented (Sousa and Voss, 2008). The framework developed in this study supports such a systems approach, i.e. by considering the context, the interventions, and the impact factors and their interdependencies at once.

6.5 LIMITATIONS

This study is not without limitations. The domain limitations outlined in the Literature Review, in P1, and in the Methodology chapter have limited the focus of this study. In terms of the investigated case studies, the national context is limited to a Danish and US setting. Moreover, the case study hospitals are all non-profit hospitals; the US hospital is owned by a non-profit organization and the Danish hospitals are public hospitals. Furthermore, the types of healthcare logistics processes investigated are limited to three types of processes; bed logistics, hospital cleaning and pharmaceutical distribution. However, the hospital cleaning case was only investigated as a separate case study for a Danish setting, although the hospital cleaning process was embedded in the US bed logistics case study. Thus, the domain of the study mainly focuses on materials flows with limited focus on patient flows. Furthermore, the distribution of services is included in the domain exemplified by the hospital cleaning case. Other types of flows such as staff flows and reverse flows have not been considered.

The SC focus of this study is mainly on the internal SC with limited focus on the link to the first tier supplier. The field of procurement was therefore not a focal area of this study but was included in relation to replenishment activities. Furthermore, areas such as telemedicine and outsourcing have not been explored due to the main focus being within hospital boundaries.

In terms of methodology, the use of quantitative methods was limited. Methods related to route optimization, forecasting and scheduling have not been included. The quantitative methods applied in the study were limited to the ranking of impact factors based on a small population of respondents. One of the limitations related to ranking is that the same type of ranking is not provided for all processes, i.e. impact factors were not ranked for the hospital cleaning case and the ANP method was used to rank the impact factors in the Danish pharmaceutical distribution case.

The catalog of interventions provided in this study is limited to the interventions reported in literature and identified in the case studies. The rapid development of technologies and developments within research and other industries in the fields of BPM, logistics and SCM and organizational management will at some point render the catalog of interventions obsolete and will need to be updated regularly to reflect state-of-the-art.

The types of investigated interventions were limited to interventions related to BPM, logistics and SCM, technologies and organizational structure. Other types of interventions, e.g. related to culture, leadership styles and financial incentive programs, were therefore not included. Furthermore, the investigation of ICTs such as the Epic system implemented in the US hospital, which coincidentally is currently being implemented in Danish hospitals, is limited. Such IT systems are complex systems which encompass the entire hospital and all types of processes. The reasons for implementing such systems from a logistics point of view have been included in the framework, but the author of this thesis is not presumptuous enough to believe that the developed framework will provide a complete and conclusive decision to such a complex issue. However, the framework could serve as a small part of such a decision process.

The validity of the findings of this study depends on the capabilities of the respondents. A study by Callender and Grasman found that almost half of the respondents (42.8%) were of the opinion that executive managers have the required skills and knowledge of SCM (Callender and Grasman, 2010). The impact factors identified in this study were ranked by managers engaged in the investigated processes. The validity of the ranking of impact factors therefore depends on the capabilities of the managers and their ability to link the impact factors to the overall strategy of the hospital and their knowledge of what is best for the hospital from a logistics point of view.

Suggestions for future research are provided in the concluding chapter in the following.

6.6 CHAPTER SUMMARY

This chapter answered and discussed the research questions investigated in this study. In relation to RQ1, healthcare logistics processes were characterized in terms of challenges and their composite elements, i.e. process steps, technologies, logistics and SCM aspects, and organizational structure. In answering RQ2, the factors impacting the design of healthcare logistics processes were presented. For RQ3, the application of the impact factors in a decision process was discussed in terms of benchmarking, performance measurement, and the assessment of possible interventions. Finally, the meta-RQ was answered based on the answers of the RQs and subsequently discussed in relation to contingency theory.

7 CONCLUSIONS AND FUTURE RESEARCH

This chapter concludes on the findings of this study and offers suggestions for future research. The chapter is structured as follows. First, the research questions are answered in the concluding remarks. An account of the contributions to research is then provided, followed by an assessment of the practical implications of the study. Finally, a chapter summary is provided.

7.1 CONCLUDING REMARKS

The rising costs of healthcare provision and the increasing demand for high quality care at a reasonable cost provide the initial motivation of this study. Logistics processes offer significant potential for cost reductions in hospitals and are the focus of this research.

Case studies were conducted at five Danish hospitals and one US hospital to investigate how healthcare logistics processes can be improved. A multiple case study at five Danish hospitals was conducted to examine the bed logistics process in a Danish hospital setting. A case study of the hospital cleaning process was then carried out at the primary Danish case hospital, followed by a study of the pharmaceutical distribution process at the same hospital. Two case studies were then conducted at a US hospital investigating the bed logistics process and pharmaceutical distribution process, respectively. Based on the case studies, the research questions of this study were investigated. Each of these research questions is answered in the following.

> ***Meta-RQ:*** *How can hospitals improve their logistical processes to ensure that the process design and performance fit the needs and preferences of a hospital?*

The overall RQ investigated in this study is captured in the meta-RQ above. The meta-RQ is answered through three RQs and their underlying SQs. Each of the RQs is answered in the following.

> ***RQ1:*** *How can healthcare logistics processes be characterized in terms of challenges and composite design elements?*

Healthcare logistics processes were characterized in terms of challenges and their constituent elements in terms of process steps, logistics and SCM aspects, implemented technologies, and organizational structure. Nine types of benefits across the different types of interventions were identified. The benefits of interventions identified in the case studies are reflected in the impact factors identified in this study except for the impact factors *downtime and maintenance* and *utilization of technologies.*

Contingent factors determining the circumstances under which implementation of possible interventions is suitable were identified in literature. The identified contingent factors have only been identified for logistics/SCM and technological interventions in the literature review. Moreover, seven contingent factors were identified in the case studies.

> ***RQ2:*** *Which factors should decision makers consider when improving healthcare logistics processes?*

Based on the case studies, 24 impact factors were identified which should be considered when improving healthcare logistics processes. The identified impact factors influence the design of healthcare logistics processes in terms of four constituent elements, i.e. process steps, logistics and SCM aspects, technologies and organizational structure. The impact factors were ranked according to the importance for improving healthcare logistics processes. Differences in the importance of impact factors were identified for specific process types and country settings. Furthermore, the case studies suggested a number of interrelations between the impact factors. When implementing interventions, these relations should be considered to understand the impact on the system. Based on literature, an additional seven impact factors were identified. Yet another four impact factors could be added for technologies based on the discussion of literature.

> ***RQ3:*** *How can the identified impact factors be used to assess healthcare logistics systems?*

A framework was developed for assessing alternative interventions. The framework consists of six steps and enables managers to select the intervention most appropriate for the circumstances in which the hospital operates. Furthermore, a methodology for benchmarking healthcare logistics was proposed and suggestions for performance measures provided.

The overall meta-RQ investigated in this study has been answered through the RQs above. Thus, challenges have been identified, a catalog of interventions has been provided, and a framework to assure best fit of a solution for a hospital has been developed. However, the findings of this study are subject to limitations. The most significant ones are the limited types of processes for which this study was conducted, i.e. bed logistics, hospital cleaning and pharmaceutical distribution, and the limited country settings where the case studies took place, i.e. Denmark and the US.

7.2 CONTRIBUTIONS TO RESEARCH

In the following, the contributions to research of this study are presented. Each contribution relates to improving healthcare logistics processes.

Enfolding of literature. The first contribution of this thesis is establishing the state of healthcare logistics literature. Literature in this field has been enfolded and four themes have been identified: 1) BPM, 2) logistics and SCM, 3) technologies and 4) organizational structure. Each of the identified interventions for improving healthcare logistics processes relates to one of the four identified themes. Furthermore, a synthesis of what literature has to offer in terms of improving healthcare logistics processes was provided. Finally, an agenda for future research was developed based on the literature review.

Empirical evidence. In addition to the theoretical evidence provided in the literature review for improving healthcare logistics processes, empirical evidence is provided in the case studies. Thus, the empirical evidence supports existing knowledge and provides new insights as to how to improve healthcare logistics processes.

Identification of challenges. Challenges inherent to logistics processes in hospitals were identified based on extant literature and the conducted case studies. The identification of challenges allows for addressing those challenges through interventions.

Catalog of interventions. Different types of interventions were identified and classified based on literature and case studies. The types of interventions considered in this study relate to BPM, logistics and SCM concepts, technologies, and organizational structure. Furthermore, the benefits of each intervention were identified.

List of contingent factors. A list of contingent factors for the suitability of interventions is provided. The contingent factors indicate under which circumstances interventions are suitable in a healthcare logistics context.

Set of impact factors. A set of impact factors for improving healthcare logistics processes were identified based on the case studies. These impact factors were ranked according to the importance for improving healthcare logistics processes. In addition, relations between impact factors were suggested based on the case studies. Additional suggestions for impact factors based on literature were provided in the Discussion.

Framework. A framework was developed for improving healthcare logistics processes. The framework is both theoretically and empirically founded. The framework serves as a tool for assessing suitable interventions to improve healthcare logistics processes. The framework allows managers to make an informed decision, taking the context of the hospital into account.

Filling the research gap. This study contributes to the limited field of healthcare logistics research. Within the healthcare logistics domain, this study contributes to four different streams of literature:

- BPM literature
- Logistics and SCM literature
- Technology assessment and justification literature
- Human factors and organizational management literature

The literature review revealed the gaps in healthcare logistics literature and this study is an attempt to fill part of that research gap. Regarding BPM literature, this study particularly contributes to the aspects of performance measurement, benchmarking and continuous improvement. Regarding logistics and SCM literature, a method was developed for assessing the design of the internal hospital SC. Furthermore, a method for assessing and justifying the implementation of technologies in a healthcare logistics process is provided. Finally, in relation to the organizational aspect, metrics for measuring staff performance were developed and the importance of employee retention and employee absenteeism for the quality of healthcare logistics processes emphasized.

7.3 PRACTICAL IMPLICATIONS

Given the research aim to *"provide theoretically and empirically based evidence for improving healthcare logistics processes […]"*, this begs the question: What should practitioners do differently now? The practical implications of this study are therefore discussed in the following.

First and foremost, this study provides a framework for managers to make an informed decision to improve healthcare logistics processes given the context of a hospital. A list of the main challenges in healthcare logistics processes is provided, which can help managers identify challenges inherent to their processes and help focus attention on any improvement efforts. To address challenges and help improve healthcare logistics processes in general, a catalog of interventions is provided. Based on this catalog of interventions, decision makers can identify the most suitable improvement interventions given the circumstances of the hospital. The circumstances under which to implement changes, i.e. the contextual variables, are provided to guide the decision. Thus, the identified contingent factors help managers narrow down the number of interventions which are relevant to the situation of the manager.

The findings of this study provide insights about the factors impacting the design of healthcare logistics processes or, put differently, the selection of interventions to be implemented in a healthcare logistics process. The ranking of the identified impact factors as decision criteria enables context specific decision making based on the developed framework. Based on the ranking of impact factors as decision criteria, managers can prioritize the list of interventions, which has already been narrowed down based on the contingent factors.

Ranking of impact factors as decision criteria may differ across hospitals, but the findings of this study suggest that patterns exist for certain types of processes. The prioritization of impact factors provided in this thesis can help managers determine where to focus their improvement efforts.

The identified impact factors can help managers think about and determine whether their own priorities may differ from those identified in this study. Priorities may be specific to a particular process or a hospital, which the framework allows to be taken into account. Furthermore, the suggested interrelations between impact factors can help managers understand the implications of interventions and view healthcare processes holistically as part of a system.

The ranking of impact factors provides another application of impact factors, namely benchmarking. The ranked impact factors enable the provided methodology for benchmarking and measuring the performance of healthcare logistics processes.

7.4 Suggestions for future research

Suggestions for future research are based on the literature review conducted in this thesis and P1. Furthermore, suggestions for future research are provided based on the limitations of this study.

7.4.1 Research agenda emerging from the literature review

Although this study has contributed to filling part of the gap identified in the thesis literature review and P1, much research is still needed to fully understand each of the aspects of this gap.

Methods. The most prevalent research method applied in the reviewed healthcare logistics literature is the case study method. Other literature reviews have focused on the quantitative studies of the field (Dobrzykowski et al., 2014), which have focused on mathematical modelling. More research is needed using surveys or mixed methods. However, given the maturity level of the field, more qualitative research may be needed to form hypotheses to be tested through statistical analyses.

Clear definitions. Concepts such as JIT, stockless and VMI solutions need clear definitions in healthcare logistics literature as there seems to be some disagreement on the matter.

BPM. Particular opportunities for future research include the investigation of process types other than the distribution of pharmaceutical products, blood products and sterile supplies. More research is needed on BPM, particularly for approaches and tools not reported in the literature of the field, e.g. TQM and lean.

Logistics and SCM concepts. Logistics and SCM together with technologies in healthcare logistics are the most investigated themes identified in the reviewed literature. Logistics and SCM topics such as SC integration and logistics and SC innovation have received little attention in literature. Other logistics concepts not investigated in the field such as agile, lean and leagile SCs could provide opportunities for future research.

Technologies. In terms of technologies, the full potential of RFID is yet to be explored. Furthermore, the potential applications of new types of technologies yet to be explored in the field would provide novel opportunities for research.

Organizational aspect. The least researched topic is the organizational aspects of healthcare logistics with rich opportunities for future research. The exploration of the human component in particular is much needed in the field (Stanger et al., 2012).

Inter-disciplinary research. The interdisciplinary nature of the field calls for more research combining theories from different research fields.

Contingent factors. The identified contingent factors mainly relate to logistics and SCM and technological interventions. Thus, contingent factors should be identified for other types of interventions.

Benefits. The benefits of each type of intervention should be mapped to a larger extent by considering literature outside the healthcare logistics field.

Learning from other industries. The field of healthcare logistics could learn from other fields which are further ahead in terms of process design and process performance.

7.4.2 Research agenda emerging from the empirical study

Suggestions for future research based on the limitations of this study are provided in the following.

Testing contexts. This study was conducted for a Danish and US setting and for three types of processes, namely the bed logistics process, the hospital cleaning process and the pharmaceutical distribution process. Similar studies should be made for other healthcare logistics processes and country settings. Moreover, the impact factors only validated for the US setting should also be tested for a Danish setting. In addition, the findings of this study should be tested on for-profit hospitals. Finally, the impact factors identified in literature should be tested as part of the developed framework.

Testing the method. A method for benchmarking healthcare logistics processes was developed in P4 and should be tested on an actual case. Furthermore, the framework developed in this thesis should be tested in an actual decision process through a longitudinal case study or action research.

Characterizing interventions. Each of the identified interventions could be characterized in terms of each impact factor to enable a direct match between interventions and a hospital's prioritized impact factors.

Adding a change management perspective. For the implementation of interventions, the change management aspect is important to ensure buy-in from logistics staff and other parts of the organization. Change management may already be considered in the decision to select interventions to be implemented. *Features and ease of use* is considered in the developed framework, but other aspects could be beneficial to consider at an early stage to ensure the successful implementation of an intervention.

Applying quantitative methods. The findings of this study are suitable to be tested using more quantitative methods, particularly with regard to three aspects. First, the suggested interdependencies between impact factors identified in this study need further validation and the suggested correlation between impact factors could be tested as hypotheses using statistical analysis. Second, the additional impact factors identified in literature should be ranked alongside the impact factors identified in the empirical study. Third, the identified impact factors should be ranked based on a larger population of respondents.

7.5 Chapter summary

This chapter summarized the findings of the study by answering each of the investigated research questions. Contributions to research were subsequently explicated and an assessment of the practical implications of the findings of this study provided. Suggestions for future research were offered based on both the conducted literature review and the empirical study.

8 REFLECTIONS

In this brief chapter, reflections of the author on the research conducted in this study are offered. These reflect opinions, ponderings, surprises and hopes for the future for the field of healthcare logistics.

Most of the fieldwork conducted in this research project took place at the main Danish case study hospital, which funded part of the research project. During the course of the project, regular meetings were held with the logistics managers of the Danish hospital to make sure the project stayed on track. Additional reports were provided to the case study hospital with recommendations on how to address their immediate challenges. It is to be expected that such reports, recommendations and support to the organization will be conducted during a PhD, although not directly part of the research outcome. It is then the responsibility of the case study company to decide which recommendations they wish to implement and is no longer in the hands of the researcher. As noted by Creswell, research consists of posing a question, collecting data to answer the question, and finally presenting an answer to the question (Creswell and Plano Clark, 2011). Unfortunately, none of the recommendations were implemented during the course of the PhD, which could be attributed to a number of reasons. First, the hospital experienced a change in management, which had therefore not been part of the initial framing of the research project and ongoing discussions. Second, as experienced by several public institutions, the financial aspect provides a constraint, and some of the recommendations would require an investment that was not possible. Third, other projects were ongoing in the hospital region regarding the possible implementation of RFID, which did not reach a definitive decision or guidelines for future use. Fourth, the hospital was in the midst of expanding with a new building, which would ultimately dictate the design of the future supply chain and logistics processes within the hospital. It was always the hope that the hospital would utilize the knowledge gained from the research project to improve their logistical setup, but circumstances did not seem to be in favor of such developments at the time being. The research outcome of this project has been four journal papers and three conference papers, which exceeds the initial expectations of the project.

During the PhD, a six month external research stay was carried out in Cleveland, Ohio in the US in collaboration with Case Western Reserve University and the US case study hospital. The US hospital mostly provided inspiration for best practices that could be applied in a Danish healthcare setting. During the research stay, I not only had the opportunity to investigate the case study processes but also to learn about the US healthcare system, continuous improvement and operational excellence which were such an integrate part of the hospital. Furthermore, I had the opportunity to provide support in ongoing projects, which also helped me understand how to improve not only logistics processes in hospitals, but processes in general, including patient treatment and administrative tasks. The external research stay provided a better understanding of how healthcare systems in other countries work, especially a country whose healthcare system is often referred to both in academia and the industry.

In terms of research findings, one surprising aspect was the importance the organizational and human resource aspects turned out to have for the findings of this study. Initially, the focus of this research project was more toward technologies, but shifted into a broader consideration of improvement efforts. Another surprise was the finding that the research field of healthcare logistics is relatively limited and that logistics processes in hospitals lag far behind the manufacturing industry, even more so in Denmark than in the US. The large gap between the Danish and US hospitals in terms of logistical capabilities were surprising. Hospitals could learn a lot from knowledge sharing between hospitals and from benchmarking within and across industries and country borders. Hopefully, hospital logistics will receive the attention it deserves and be recognized by the remaining organization as an area of strategic importance rather than merely being viewed as a cost center – although this change in perception does seem to be underway.

The focus in society on the provision of quality care and at the same time cost containment provides a good incentive for further research in terms of what the operations management field can offer, not only for logistics processes, but for any aspect of hospital operations. Continued research in the field is therefore both expected and useful in providing high quality care affordably.

Doing a PhD has been an immense privilege for me and I am grateful to have had the opportunity to spend three years on delving into such an interesting research topic. It is my hope that the findings of this research project can result in better healthcare logistics processes and ultimately better care for patients.

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APPENDIX

APPENDIX A: BENEFITS OF INTERVENTIONS

Table A1. Overview of benefits achieved through BPM interventions

Benefits	BPR	Cellular operations	Performance measurement	Benchmarking	Process standardization
Process performance and cost savings					
Increased efficiency	(Kumar et al., 2008)	(Parnaby and Towill, 2009)	(Ritchie et al., 2000)		(Ritchie et al., 2000)
Improved effectiveness			(Ritchie et al., 2000)		(Ritchie et al., 2000)
Cost savings	(Kumar et al., 2008)	(Parnaby and Towill, 2009)		(Poulin, 2003)	
Improved SC and hospital performance			(Ritchie et al., 2000)	(Aptel and Pourjalali, 2001)	
Quality					
Improved service levels					(Fredendall et al., 2009)
Increased reliability and routinization				(Böhme et al., 2016)	
Flow management					
Improved operational flow	(Kumar et al., 2008)	(Parnaby and Towill, 2009)			(Fredendall et al., 2009; Ritchie et al., 2000)
Improved reverse logistics			(Ritchie et al., 2000)		
Improved planning and control			(Ritchie et al., 2000)		
Improved administrative processes		(Parnaby and Towill, 2009)			

Table A2. Overview of benefits achieved through logistics and SCM interventions

Benefits	**Suitable RP**	**JIT**	**Stockless**	**VMI**	**SD**	**SC integration**	**SC/ logistics innov.**	**Responsive SCs**
Process performance and cost savings								
Increased efficiency		(Heinbuch, 1995)		(Guimarães et al., 2013; Kumar et al., 2008)		(Brennan, 1998; Landry and Philippe, 2004)	(Kumar et al., 2008; Lee et al., 2011)	
Lead time						(Chen et al., 2013)		
Cost savings	(Beier, 1995; Landry and Philippe, 2004; Wang et al., 2015)	(Aptel and Pourjalali, 2001; Heinbuch, 1995; Jarrett, 1998; Kim and Schniederjans, 1993; Kumar et al., 2008)	(Kim and Schniederjans, 1993; Wilson et al., 1992)	(Guimarães et al., 2013; Hemmelmayr et al., 2009; Haavik, 2000)		(Breen and Crawford, 2005; Chen et al., 2013)	(Kumar et al., 2008; Lega et al., 2012; Su et al., 2011)	
Improved SC and hospital performance	(Chen et al., 2013)					(Böhme et al., 2016)	(Lee et al., 2011; Lega et al., 2012)	
Improved flexibility/ responsiveness				(Guimarães et al., 2013)		(Chen et al., 2013)		(Callender and Grasman, 2010)
Quality								
Error reductions		(Persona et al., 2008)		(Haavik, 2000)				
Improved service levels		(Heinbuch, 1995; Kim and Schniederjans, 1993)	(Kim and Schniederjans, 1993)	(Guimarães et al., 2013)		(Chen et al., 2013)	(Lega et al., 2012)	
Increased reliability and routinization							(Lega et al., 2012)	
Improved data accuracy				(Guimarães et al., 2013)				
Inventory management								

Improved demand and supply variability management	(Beier, 1995; Rautonen, 2007; Wang et al., 2015)	(Jarrett, 1998)	(Danas et al., 2002)					
Improved product availability	(Beier, 1995; Rautonen, 2007)			(Guimarães et al., 2013)				
Stock level reductions	(Beier, 1995; Fontaine et al., 2009; Nicholson et al., 2004; Wang et al., 2015)	(Aptel and Pourjalali, 2001; Kumar et al., 2008; Persona et al., 2008)	(Kim and Schniederjans, 1993; Marino, 1998; Wilson et al., 1992)	(Haavik, 2000)	(Pinna et al., 2015)			
Improved inventory visibility				(Guimarães et al., 2013)				
Reductions in theft and wasted products				(Guimarães et al., 2013)				
Flow management								
Improved operational flows		(Heinbuch, 1995)				(Böhme et al., 2016)		
Improved planning and control							(Su et al., 2011)	
Improved administrative processes						(Breen and Crawford, 2005)		
Patient care								
Increased patient care quality and safety				(Guimarães et al., 2013)				
Staff								
Elimination of manual processes				(Guimarães et al., 2013; Haavik, 2000)		(Breen and Crawford, 2005)		
Time savings	(Landry and	(Persona et al., 2008)	(Wilson et al., 1992)	(Guimarães et al., 2013)	(Pinna et	(Breen and		

	Philippe, 2004)				al., 2015)	Crawford, 2005)		
Procurement								
Reduced order frequency and volume		(Persona et al., 2008)						
Reduced consumption and over-buying		(Heinbuch, 1995; Persona et al., 2008)						
Improved supplier integration and relationships		(Aptel and Pourjalali, 2001)	(Wilson et al., 1992)	(Guimarães et al., 2013)		(Breen and Crawford, 2005; Böhme et al., 2016; Chen et al., 2013)	(Lee et al., 2011; Lega et al., 2012; Su et al., 2011)	
Information management and supply chain coordination								
Improved SC info sharing and processing				(Guimarães et al., 2013)		(Breen and Crawford, 2005)		

Table A3. Overview of benefits achieved through technological interventions

Benefits	Automated transport	ASR	Barcodes	RFID	ICT systems
Process performance and cost savings					
Increased efficiency*			(Romero and Lefebvre, 2015)*	(Anand and Wamba, 2013; Bendavid et al., 2012; Yazici, 2014) (Romero and Lefebvre, 2015)*	(Gomez et al., 2015; Kumar et al., 2008; Pan and Pokharel, 2007; Spens and Bask, 2002; Xie et al., 2016)
Increased productivity				(Anand and Wamba, 2013; Bendavid et al., 2010, 2012; Coustasse et al., 2013)	(Kumar et al., 2008; Su et al., 2011)
Shorter processing time				(Kumar and Rahman, 2014)	(Kumar et al., 2008; Pan and Pokharel, 2007; Su et al., 2011)
Shorter cycle time*			(Romero and Lefebvre, 2015)*	(Romero and Lefebvre, 2015)*	(Kumar et al., 2008)
Lead time*	(Landry and Philippe, 2004)*				
Cost savings*		(Bourcier et al., 2016)	(Romero and Lefebvre, 2015)*	(Anand and Wamba, 2013; Bendavid et al., 2010; Coustasse et al., 2013; Van de Klundert et al., 2008; Kumar and Rahman, 2014; Yao et al., 2012) (Romero and Lefebvre, 2015)*	(Aptel and Pourjalali, 2001; Breen and Crawford, 2005; Pan and Pokharel, 2007; Xie et al., 2016)
Increased device utilization				(Coustasse et al., 2013; Kumar and Rahman, 2014; Xie et al., 2016)	(Xie et al., 2016)
Quality					
Error reductions			(Maviglia et al., 2007)	(Anand and Wamba, 2013; Bendavid et al., 2010, 2012; Chircu et al., 2014; Coustasse et al., 2013; Kumar and Rahman, 2014)	(Haavik, 2000; Pan and Pokharel, 2007; Xie et al., 2016)
Improved service levels				(Anand and Wamba, 2013)	(Kumar et al., 2008; Pan and Pokharel, 2007; Xie et al., 2016)
Increased reliability and routinization				(Anand and Wamba, 2013)	(Su et al., 2011)
Reductions in counterfeit drugs				(Chircu et al., 2014; Yao et al., 2012)	
Improved data accuracy*		(Rosales et al., 2014)	(Romero and Lefebvre,	(Bendavid et al., 2012)(Romero and Lefebvre, 2015)*	(Su et al., 2011; Xie et al., 2016)

			2015)*		
Inventory management					
Improved product availability		(Rosales et al., 2014)		(Bendavid et al., 2012; Coustasse et al., 2013; Kumar and Rahman, 2014; Xie et al., 2016)	
Stock level reductions		(Bourcier et al., 2016; Rosales et al., 2014)		(Bendavid et al., 2012; Çakici et al., 2011; Kumar and Rahman, 2014)	(Aptel and Pourjalali, 2001; Perera et al., 2009; Xie et al., 2016)
Improved inventory visibility*		(Rosales et al., 2014)	(Romero and Lefebvre, 2015)*	(Romero and Lefebvre, 2015)*	
Fast ID of end-of-life/obsolete stock					(Dunbar, 2015; Xie et al., 2016)
Reductions in theft and wasted products*			(Romero and Lefebvre, 2015)*	(Anand and Wamba, 2013; Bendavid et al., 2010, 2012; Çakici et al., 2011; Coustasse et al., 2013; Kumar and Rahman, 2014) (Romero and Lefebvre, 2015)*	(Dunbar, 2015; Gomez et al., 2015; Perera et al., 2009; Xie et al., 2016)
Reduced rate of emergency orders		(Bourcier et al., 2016)			
Improved demand and supply variability management					(Spens and Bask, 2002)
Flow management					
Improved operational flows*				(Kumar and Rahman, 2014)	(Xie et al., 2016)*
Improved reverse logistics*			(Romero and Lefebvre, 2015)*	(Xie et al., 2016) (Romero and Lefebvre, 2015)*	(Xie et al., 2016)
Improved visibility of flows				(Anand and Wamba, 2013; Bendavid et al., 2012; Van de Klundert et al., 2008; Kumar and Rahman, 2014)	
Reductions in waiting time	(Jørgensen et al., 2013)			(Kumar and Rahman, 2014)	
Improved planning and control*				(Yazici, 2014)	(Spens and Bask, 2002)(Xie et al., 2016)*

Improved administrative processes		(Rosales et al., 2014)		(Anand and Wamba, 2013; Coustasse et al., 2013)	(Breen and Crawford, 2005; Pan and Pokharel, 2007)
Patient care					
Reductions in delays for patients				(Kumar and Rahman, 2014)	
Increased patient care quality and safety*			(Maviglia et al., 2007) (Romero and Lefebvre, 2015)*	(Anand and Wamba, 2013; Bendavid et al., 2010; Coustasse et al., 2013; Xie et al., 2016; Yao et al., 2012) (Romero and Lefebvre, 2015)*	(Xie et al., 2016)
Compliance					
Enhanced documentation				(Chircu et al., 2014)	
Temperature assurance				(Chircu et al., 2014)	
Improved maintenance				(Bendavid et al., 2010; Xie et al., 2016)	(Xie et al., 2016)
Staff					
Improved work conditions and staff satisfaction		(Rosales et al., 2014)		(Yazici, 2014)	
Elimination of manual processes	(Kumar and Rahman, 2014)	(Bourcier et al., 2016)		(Anand and Wamba, 2013; Bendavid et al., 2012; Kumar and Rahman, 2014)	(Breen and Crawford, 2005; Haavik, 2000)
Time savings	(Bloss, 2011)	(Bourcier et al., 2016)		(Anand and Wamba, 2013; Bendavid et al., 2010, 2012; Coustasse et al., 2013; Kumar and Rahman, 2014; Yao et al., 2012)	(Breen and Crawford, 2005; Xie et al., 2016)
Procurement					
Improved readiness of purchase orders*			(Romero and Lefebvre, 2015)*	(Romero and Lefebvre, 2015)*	
Reduced consumption and overbuying				(Anand and Wamba, 2013; Kumar and Rahman, 2014)	
Reductions in back orders				(Çakici et al., 2011)	
Improved supplier integration and relationships				(Chircu et al., 2014)	(Aptel and Pourjalali, 2001; Breen and Crawford, 2005; Callender and Grasman, 2010; Chen et al., 2013; Kumar et al.,

					2008)
Information management and supply chain coordination					
Improved information storage*				(Çakici et al., 2011)	(Xie et al., 2016)*
Real-time data access				(Chircu et al., 2014; Wieser, 2011; Yao et al., 2012; Yazici, 2014)	(Breen and Crawford, 2005)
Improved SC info sharing and processing				(Bendavid et al., 2012)	(Breen and Crawford, 2005; Spens and Bask, 2002)(Xie et al., 2016)*
Improved SC communication *					(Xie et al., 2016)*
Improved CPFR*					(Xie et al., 2016)*

”*” = reason for implementation / decision criterion

Table A4. Overview of benefits achieved through organizational interventions

Benefits	Organization of logistics activities	Human resource management	Centralization vs. decentralization	Social and organizational setting
Process performance and cost savings				
Increase efficiency			(Kumar et al., 2008)	(Böhme et al., 2016)
Cost savings			(Kumar et al., 2008; Landry and Philippe, 2004; Lega et al., 2012)	
Improved SC and hospital performance		(Landry and Philippe, 2004; Stanger et al., 2012)	(Landry and Philippe, 2004; Lega et al., 2012; de Vries, 2011)	(Böhme et al., 2016; McKone-Sweet et al., 2005)
Quality				
Improved service levels			(Lega et al., 2012)	
Increased reliability and routinization			(Lega et al., 2012)	
Staff				
Time savings	(Bloss, 2011; Landry and Philippe, 2004)		(Landry and Philippe, 2004)	
Flow management				
Improved reverse logistics				(Ritchie et al., 2000)
Patient care				
Increased patient care quality and safety				(Böhme et al., 2016)
Procurement				
Improved supplier integration and relationships			(Lega et al., 2012)	

APPENDIX B: EXAMPLE OF INTERVIEW GUIDE

Preparation

Background: The project focuses on how to improve logistical processes in hospitals, particularly through the use of technologies and changes to the process steps. The bed logistics process and pharmaceutical distribution process are in focus.

Purpose: To learn about the process, the challenges in the process, the reasons for implementing improvement initiatives (process changes, implementation of technologies etc.), and the effects of these changes (on logistics, technology, structure, and procedure).

Interview questions

Background questions

1) What is your role?
2) What are the responsibilities of your department?
    a. Which tasks do you undertake?
    b. Do you have different units in your department?
    c. Do you have an organizational chart available for me to see?
    d. How many people work there?
3) Describe the process steps of the process

The use of technologies and the implementation of process changes

4) Which technologies / process changes have you implemented?
5) When did you start using these technologies / process changes?
6) What do you use the technologies for?
7) Why did you decide to use these technologies / process changes?
    a. What were the main drivers for deciding to use that technology rather than other technologies?
    b. Do the reasons vary depending on the process?
    c. Which challenges did you hope to overcome by implementing technologies?
    d. Which decision parameters did you use?
8) Validate decision indicators in framework – were others used? Where some not used?
9) Did you test other types of technologies in those processes before implementing?
10) What were the main challenges in the process before you implemented the technologies / made process changes?
11) What are the main challenges for the processes now?
12) What challenges have you had with the technologies?
13) Have any of the technologies that you have implemented / tried to implement failed?

a. If so, why?

14) What have been the main benefits of implementing technologies?
15) What good or bad effects have you experienced after implementing the technologies or other improvement initiatives?
16) How do employees interact with the technologies?
17) When would you choose to use technologies over other types of improvement?
18) When would you rather use human resources?
19) How have the employees received the use of technologies?

Data and performance measurement

20) Do you use any KPIs to measure process performance?
    a. If yes, which KPIs do you use?
    b. Why have you chosen those KPIs?
    c. How do you capture data to measure the KPIs? (RFID, barcodes?)
    d. Have your KPIs improved since implementing technologies / change initiatives?
        i. Are the improvements also due to other improvement initiatives?
        ii. How much did the KPIs improve?
21) Do you consider the process a good process?
    a. Why / why not?
22) Is the process best practice?
    a. Why / why not?
    b. What characterizes the process?

Future prospects

23) Do you see the implemented technologies as something you would invest in in the future or are there other technologies that are more interesting?
24) If you could have three wishes granted for the processes, what would that be?
25) Any changes in pipeline?

Documents and further research

26) Do you have any process maps that I can have a look at?
27) Do you have any presentations/proposals for implementing AGVs that I may see?
28) Do you have any executive reports on performance that I may see?
29) Can I use my findings for publication?
30) Further interviews and observations possible?
    a. Process observations possible?
    b. Employee shadowing possible?
    c. Follow-up interviews possible?
31) Thank you for your time – anything to add?

APPENDIX C: EXAMPLE OF OBSERVATION GUIDE

Preparations: Possibly findings from previous case study

Brief background: PhD project at the Technical University of Denmark. The project focuses on how to improve logistical processes in hospitals, particularly through the use of technologies. I've looked at three different processes: 1) bed logistics, 2) hospital cleaning, 3) drug distribution. Some of these interviews are part of my research.

Purpose of observation: To learn about the process, the challenges in the process, the reasons for implementing improvement initiatives (process changes, implementation of technologies etc.), and the effects of these changes (on logistics, technology, structure, and procedure).

Observation guide

Observations / exploratory questions

1) What are the process steps?
2) Do you have a process map, I can see?
3) How many rounds / trips / products are performed / handled every day in the process?
4) How many people work in each process step?
5) What are the challenges in the process?
6) Are there any quality issues / challenges?
7) What technologies are used in the process?
8) How are the technologies used?
9) Why did you choose these technologies?
10) What change initiatives have you implemented over the years?
11) How have the employees received the changes / technologies?
12) Is it a good process?
    a. Would you say it is best practice?
    b. What makes it a good process / best practice?
13) What changes would you wish for?
14) Do you have any changes in pipeline?

Follow-up if possible

15) Further interviews and observations possible?
    a. Process observation (current)
    b. Interview (with manager?) to ask about decision process
    c. Employee shadowing
    d. Two follow-up interviews (with manager)

APPENDIX D: EXAMPLE OF STRUCTURED INTERVIEW GUIDE/SURVEY QUESTIONS

Table D depicts the survey sent out to decision makers in the bed logistics and pharmaceutical logistics case studies. The respondents were asked to weight the decision criteria on a 0-10 scale according to their importance when improve healthcare logistics processes.

Table D. Validation of identified decision criteria

Decision criterion	**Description**	**Weight (0-10)**
Lead time	Time from order to delivery.	
Value-added time	% of lead time adding value.	
Security of supply	Ensuring the right amount at the right time.	
Traceability	Enabling track and trace.	
Degree of automation	How automated is the process?	
Information management	The ability to collect, analyze and communicate data.	
Environmental considerations	Sustainable use of energy, chemicals, renewable materials etc.	
Risk of mistakes	Likelihood of mistakes occurring.	
Consistency	Standardization of the process and process output.	
Future proofing	Will the solution sustain in five years? Is it flexible?	
Impact on related processes	Negative and positive impact on other processes. E.g. other use for technology or increased workload for others.	
Output quality	Quality of product/service delivered.	
Competence shift (handovers)	Number of handovers in the process.	
Competence match	Do the competencies of the employees match the needs of the new process or is training needed?	
Unnecessary process	Can the process be avoided?	
Employee engagement	Is the employee motivated to perform the job? Is an incentive provided?	
Employee work conditions	Employee safety, work load, strenuous work, ergonomics, physical and psychological work environment.	

APPENDIX E: RELATIONS BETWEEN IMPACT FACTORS

Table E1. Identified effects of Technology factors on other factors

Effect of *Technology* factors	**Effect on**	**Nature of effect**	**Case examples**
Features and ease of use	*Output quality (P)*	+	*Case A:* The features of the washing machines improve quality of washed bed. *Case C/E*: Barcodes ensure right drug and patient.
	Effect on related processes (P)	+/-	*Case A:* The monorail requires that other staff groups adhere to guidelines to avoid disruptions; washing machines can be used for other items than beds. *Case E:* The features of the picking carousel and barcodes used in pharmaceutical distribution affects the patient safety and the process for administering drugs to patients.
	Employee engagement (S)	+/-	*Case A:* Easy-to-use technologies motivate employees to use technologies, whereas time consuming technologies reduce the motivation to use the technology, e.g. a crane for lifting mattresses. *Case E*: Repetitive and dull tasks can be performed/supported by technologies, e.g. the picking carousel, AGVs and pneumatic tubes.
	Competence match (S)	+/-	*Case A:* New technologies and processes require training of employees; easy-to-use technologies require less training, e.g. a washing machine. *Case D:* AGVs require that each department learns how to use the system for ordering an AGV. *Case E:* Implementing picking carousels requires additional training of staff; AGVs require that each department learns how to use the system for ordering an AGV.
	Lead time (L)	+/-	*Case A:* Monorails and elevators for bed transport in primary case hospital are slower than the pace of the rest of the process. *Case D:* AGVs are slower than transport by staff. *Case E:* Picking carousel reduces processing and lead times; AGVs are slower than transport by staff.
Degree of automation	*Risk of mistakes (P)*	+	*Case A:* The use of washing machines reduces the risk of mistakes in washing beds. *Case E:* The use of barcodes reduces the risk of mistakes in drug administration.
	Consistency (P)	+	*Case A:* Washing machines increase the consistency of how beds are washed. *Case E:* Picking carousels and barcodes increase the consistency of how a process is performed because these technologies limit how the process can be conducted.
	Employee work conditions (S)	+	*Case A:* The use of washing machines reduces the amount of strenuous work; the monorail reduces the amount of hard work. *Case D:* AGVs in the US for linen reduces amount of hard work and risk of injuries. *Case E:* AGVs for transport of drugs reduce amount of hard work and risks of injuries; picking carousels makes the picking process easier for employees; pneumatic tubes decrease the amount of hard work.
	Unnecessary processes (S)	+	*Case A:* The monorail reduces the staff resources needed for transport of beds; washing machines reduce the staff resources needed for washing beds; *Case D:* AGVs reduce the staff resources needed for transporting linen. *Case E:* The picking carousel reduces the amount of staff resources needed

			for picking items.
	Competence shifts (S)	+	*Case A:* If a larger part of the process is automated, less competence shifts, i.e. handovers, need to take place, e.g. monorail transport. *Case E:* When orders and transactions are entered directly into the system and actions are automatically triggered, less human interaction and consequently handovers are needed.
Information management	*Employee engagement (S)*	+/-	*Case A:* Lead time was measured for employees to motivate employees and increase efficiency. *Case B:* Performance measures and morning meetings were used to increase performance of the cleaning process. *Case D:* Lead time was measured for transport and cleaning progress measured for cleaning to monitor and ensure progress. *Case E:* Lead times and processing times measured to improve performance.
Downtime & maintenance	*Value-added time (L)*	-	*Case A/D/E:* Downtime and maintenance of any of the technologies utilized in the case studies would reduce value-added time. Although maintenance is necessary and may prevent longer downtime than if maintenance is not carried out regularly. Two AGVs are therefore taken out for maintenance at all times.
	Security of supply (L)	-	*Case A:* If the monorail for transporting beds is out of order, it is not possible to wash the beds under regular circumstances and alternatives measures are necessary. *Case D:* If AGVs are down, linen will have to be transported manually, increasing pressure on staff. *Case E:* If the picking carousel is down, processing time for picking drugs is longer; if AGVs are down, drugs will have to be transported manually, increasing pressure on staff.

Table E2. Identified effects of Logistics factors on other factors

Effect of *Logistics* factors	**Effect on**	**Nature of effect**	**Case examples**
Traceability	*Enables information management (T)*	+	*Case A:* Being able to capture data on amount of beds cleaned enables information management and performance measurement; transporter and patient is always documented. *Case B:* Traceability is low for the hospital cleaning process, but the traceability that exists is used for performance measurement and continuous improvement. *Case C:* The transport organization has tried to enhance traceability by increasing the requirements for information shared by the employer, especially upon delivery. *Case D:* It is always known which transporter handles a patient and how long it takes. This information is used for performance evaluations. *Case E:* Traceability is high throughout the process and captured data is used for performance measurement and continuous improvement.
	Competence shifts (S)	+	*Case A:* Traceability of patient transports enables accountability; lack of traceability for transport of beds to cleaning increases mistakes and decreases accountability in competence shifts. *Case C:* Lack of traceability reduces accountability in handovers of drugs. *Case D:* Traceability in patient transport increases accountability in transfer of patient to clinical department; traceability in cleaning responsibility ensures accountability when handing over clean room to clinical department. *Case E:* Barcodes enable smooth transfers between resources and enables accountability in the process.

Table E3. Identified effects of Procedure factors on other factors

Effect of *Procedure* factors	**Effect on**	**Nature of effect**	**Case examples**
Risk of mistakes	Value-added time (L)	-	*Case A/B/C/D/E:* If risk of mistakes increases, re-work is needed to correct the errors.
	Security of supply (L)	-	*Case A:* An increase in mistakes, e.g. in handing over beds, increases risk of disruptions in bed delivery to cleaning and subsequently delivery of clean beds. *Case B/D:* Mistakes in cleaning means that the supply rate of clean rooms decreases. *Case C/E:* Risk of mistakes in the ordering process could decrease the timely delivery of drugs.
Improved output quality	Value-added time (L)	+	*Case A:* Washing beds in washing machines required more time, hence more time spent on adding value. *Case B/D:* A certain amount of time for cleaning is needed for quality assurance purposes.
	Lead time (L)	-	*Case A:* Washing beds in washing machines required more time, hence lead time increases. *Case B/D:* A certain amount of time for cleaning is needed for quality assurance purposes.

Table E4. Identified effects of Structure factors on other factors

Effect of *Structure* factors	**Effect on**	**Nature of effect**	**Case examples**
Unnecessary processes	Value-added time (L)	-	*Case A/D:* Unnecessary processes such as transport decreases value-added time ratio. *Case C:* Unnecessary repackaging of items decreases value-added time ratio.
	Lead time (L)	-	*Case A/D:* Unnecessary processes such as transport decreases lead time. *Case C:* Unnecessary repackaging of items decreases lead time.
Competence shifts	Value-added time (L)	-	*Case A:* Handovers between staff groups, e.g. beds from nurses to transporters to bed cleaners increases risk of mistakes and consequently value-added time. *Case C/E:* Proper handovers take time; handovers in the Danish case does not include sign-off, but this step takes place in the US case.
	Lead time (L)	-	*Case A:* Handovers between staff groups, e.g. beds from nurses to transporters to bed cleaners increases risk of mistakes and thus lead time due to rework. *Case C/E:* Proper handovers take time; handovers in the Danish case does not include sign-off, but this step takes place in the US case.
	Risk of mistakes (P)	-	*Case A:* Handovers have led to an increased number of mistakes from nurse to transporter to bed cleaners. *Case C:* Handovers from supplier to transporter to clinical departments means that mistakes accumulate and are identified late in the process. *Case E:* The increased risks of mistakes have been mitigated through the use of barcodes and quality checks at each handover.
	Consistency (P)	+/-	*Case A:* The use of specialized employees can increase output consistency, e.g. bed cleaners are experts in cleaning beds, transporters are experts in transport. Conversely, competence shifts increases risk of mistakes, which in turn decreases consistency.
Competence match	Value-added time (L)	+	*Case A/B/D:* Employees with the right competencies deliver room according to cleaning standards, i.e. time spent on cleaning is value-adding to a larger extent.
	Lead time (L)	+	*Case A/B/D:* Employees with the right competencies deliver room according to cleaning standards and are more efficient with their time spent.
	Consistency (P)	+	*Case A:* The use of specialized employees with the right competencies can increase output consistency, e.g. bed cleaners are experts in cleaning beds, transporters are experts in transport. Conversely, competence shifts increases risk of mistakes, which in turn decreases consistency.
	Output quality (P)	+	*Case A/B/C/D/E:* Employees with the right competencies can perform tasks according to SOPs which ensure quality; e.g. temporary cleaning staff does not perform as well as permanent staff (case B).
	Risk of mistakes (P)	+	*Case A/B/C/D/E:* If employees do not know how to perform a task properly, mistakes will inevitably follow; e.g. temporary cleaning staff does not perform as well as permanent staff (case B).
Employee engagement (S)	Output quality (P)	+	*Case A/B/C/D/E:* Employees that are motivated to perform a job will do so more diligently and according to SOPs; e.g. most transporters and nurses know how to hand over beds yet mistakes keep occurring (case A).
	Risk of mistakes (P)	+	*Case A/B/C/D/E:* Motivated employees will take more care in their work; e.g. most transporters and nurses know how to hand over beds yet mistakes keep occurring (case A).

APPENDED PAPERS

PAPER 1

Title:	How to improve healthcare logistics processes - a systematic literature review
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How to improve healthcare logistics processes - a systematic literature review

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Abstract

Purpose: The purpose of this study is to examine the interventions that health care providers can use to improve their internal logistics support processes. In addition, the study examines under which circumstances specific interventions and improvement approaches are most useful.
Design/methodology/approach: Using the systematic literature review methodology the study examined 81 selected papers published between 1992 and 2016.
Findings: An analysis of the reviewed papers revealed four categories of interventions for improving healthcare logistics processes: 1) business process management interventions (BPM), 2) logistics and supply chain management interventions (SCM), 3) technological interventions, and 4) organizational interventions. These four categories each contain a number of specific interventions. The contingent factors that determine the ideal circumstances for intervention application were determined for specific replenishment systems and for technological interventions.
Research limitations/implications: The study proposes a research agenda suggesting more research specifically on BPM and organizational interventions including contingent factors and at the intersection of SCM/logistics-organization and BPM-organization literature.
Practical implications: Practitioners within healthcare logistics can use the set of interventions and contingent factors to determine the most useful intervention type for their specific context.
Originality/value: This is the first broad literature review that studies state-of-the-art within healthcare logistics processes and their improvement.
Keywords: Logistics, materials handling, supply chain management; healthcare
Paper type: Literature review

Introduction

Healthcare systems around the world face the similar challenges of rising costs and an increasing demand for high quality care (OECD, 2015; Saltman and Figueras, 1997; WHO, 2010). More than 30 per cent of hospital expenditure relates to logistics activities (Aptel et al., 2009; McKone-Sweet et al., 2005; Poulin, 2003) and is projected to exceed labor costs in the near future (Kowalski, 2009). Experts suggest that half of the costs related to healthcare logistics could be eliminated by applying supply chain (SC) best practices (Poulin, 2003). Furthermore, logistics activities are often performed by the wrong people in a hospital (Landry and Philippe, 2004), with nurses spending as much as 30 per cent of their time on logistics activities such as finding medication and other supplies (Bloss, 2011; Landry and Philippe, 2004). Logistics activities in hospitals therefore provide significant opportunities for cost reductions (Aptel and Pourjalali, 2001; Pan and Pokharel, 2007), and improving hospital logistics could ultimately enhance quality of care (Fredendall et al., 2009; Landry and Philippe, 2004).

Logistics management is a subset of supply chain management (SCM) and has been defined by the Council of Supply Chain Management Professionals as “that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements” (Council of Supply Chain Management Professionals, 2016). SCM can be a source of competitive advantage that significantly improves financial and operational performance (Lambert et al., 1998; Li et al., 2006; Slone, 2004; Tan et al., 1999; Tracey, 1998). Manufacturing industries have realized the strategic importance of SCM and increased their focus on managing their SCs efficiently and effectively (Lambert et al., 1998; Slone, 2004; Tracey, 1998). Similarly, the view on SCM in hospitals has shifted from perceiving logistics as merely a cost center to logistics becoming a strategic asset (DeJohn, 2009). However, hospitals have been slow to adopt SCM and logistics concepts (Callender and Grasman, 2010; Radnor et al., 2012; Yasin et al., 2002), partly because hospitals are complex systems. Healthcare SCM is considered more complex than for manufacturing industries (Beier, 1995; Jarrett, 1998), and adopting SCM best practices in healthcare can therefore be problematic (de Vries and Huijsman, 2011). Thus, logistics and SCM concepts have not been systematically applied within healthcare (Towill and Christopher, 2005; Yasin et al., 2002). Moreover, the application of SCM and logistics concepts in healthcare has not always provided the expected results and managers are often left to their own experience when trying to improve processes (van Lent et al., 2012; Volland et al., 2016). Given the current state of SCM in healthcare, the healthcare industry could learn from SCM practices applied in other industries (Burt, 2006), and extant literature concerning the application of SCM and logistics practices in hospitals could provide valuable insights for logistics managers on how to improve healthcare logistics processes.

Literature reviews on the topic of healthcare logistics and SCM are limited. Volland et al. review quantitative studies on materials logistics related to patient care (Volland et al., 2016). Dobrzykowski et al. analyze literature related to the application of operations management and SCM in healthcare services and identify the major streams of literature in terms of research topics and methodologies (Dobrzykowski et al., 2014). Similarly, Souza surveys extant literature regarding the application of lean in healthcare and provides a taxonomy of lean healthcare literature (Souza, 2009). The 2012 literature review by Yao et al. and the 2013 literature review by Wamba et al. identify application areas for RFID in healthcare (Wamba et al., 2013; Yao et al., 2012). A review of quantitative studies on managing the SC of blood products is provided by Beliën and Forcé, categorizing literature according to blood product types (Beliën and Forcé, 2012). Most of the literature reviews mentioned here categorize streams of literature and map the use of different methodologies. Furthermore, some of the literature reviews focus entirely on quantitative methods. A systematic literature review of both qualitative and quantitative studies delineating what the literature prescribes for improving healthcare logistics processes is missing.

Healthcare logistics processes constitute different types of flows, including monetary, informational, materials, equipment, consumable items, patients and human resources (Fredendall et al., 2009; Landry and Philippe, 2004; Parnaby and Towill, 2009). This paper focuses on how to improve logistical processes that support the flow of materials in hospitals. Two research questions are investigated in this paper:

RQ1. What does existing literature offer in terms of how to improve healthcare logistics processes?

RQ2. What are the contingent factors that determine when different interventions and approaches for improving healthcare logistics processes are recommendable?

This study is a systematic review of healthcare logistics literature and contributes with an account of the state of research in the field and an agenda for future research. For logistics managers in hospitals, the study provides insights from the existing body of knowledge on how to improve their processes.

The paper is structured as follows. The methodology for the literature review is thoroughly described to ensure transparency on how papers were included and excluded from the study. The results are then presented in a descriptive analysis of the surveyed literature followed by a thematic analysis of the paper content. The thematic analysis identifies how healthcare logistics processes can be improved (RQ1) and when to apply different interventions and approaches for improving healthcare logistics processes (RQ2). Finally, conclusions and a proposed research agenda for future research are provided.

Method

The nature of management literature makes it difficult to provide unambiguous answers to the effectiveness of interventions. Moreover, management literature often lacks rigor and relevance. The systematic literature review ensures a more rigorous method and transparent review process that provides robust evidence from literature and raises questions for future research (Denyer and Tranfield, 2009; Tranfield et al., 2003). Articulated research questions frame and direct the systematic review and synthesis (Denyer and Tranfield, 2009; Rousseau et al., 2008; Tranfield et al., 2003). A good systematic literature review should enable practitioners to make decisions informed by the evidence provided in research (Tranfield et al., 2003). The systematic review method originated from the healthcare industry and thus fits well with the target group of this study, i.e. practitioners and researchers in healthcare logistics and management. The systematic literature review method proposed by Tranfield et al. (2003) is adopted in this study and consists of the following stages: 1) planning, 2) conducting, and 3) reporting and dissemination, each of which is described in the following.

Stage 1: Planning the literature review

In the planning stage, the literature review is scoped and planned. First, a scoping study is conducted to assess the relevance and size of literature and to ascertain how extant literature has treated the topic. Second, a review protocol is constructed that consists of the RQs, the focus of the study, the search strategy for identification of literature, and the criteria for inclusion and exclusion (Tranfield et al., 2003). The RQs posed in this study and their context and relevance are found in the Introduction. The remaining part of planning the literature review is presented in the following.

The keywords used for locating literature can be found in Table 1. The keywords in group I to IV reflect the RQs and are variations over the words 'logistics', 'healthcare', 'process', and different flow types. Initial searches showed that a large number of papers without relevance to the scope of this study dominated the search results. A list of excluding keywords was therefore identified as part of the scoping study and can be found in Table 1.

Table 1. Overview of keywords in literature search

Keywords I	**Keywords II**	**Keywords III**	**Keywords IV**	**Excluding keywords**
• Logistics • Supply chain management • Materials handling • Physical distribution	• Healthcare • Health care • Hospital	• Process • Value chain • Supply chain	• Pharmaceutical • Medicine • Drug • Medical supplies • Blood • Blood bank • Bed • Waste • Patient	• Humanitarian • Disaster • Clinical • Physician • Disease • Family planning • Home care • Pediatric • Public health research • Operations research • Operational research • Mathematical • Logistic regression analysis • Regression analysis • Malpractice

This study focuses on materials flows within hospitals and only papers considering implications for hospitals in the SC were included in the review. Thus, the reviewed papers mainly focus on internal hospital processes or the immediate SC. Papers considering the entire SC were included provided they consider implications for the focal hospital. Consequently, procurement is only considered in relation to the replenishment of hospital supplies. Finally, operations research papers investigating route and resource optimization are not relevant to this study. Based on these delimitations, a set of selection criteria were established. The inclusion criteria are as follows:

- Contributions to knowledge about how to improve healthcare logistics processes are provided
- The physical distribution of materials within a hospital is in focus
- The hospital is included as one of the foci in the SC if not the main focus
- Procurement is only relevant if related to the process of replenishing hospital supplies

In addition, the following exclusion criteria were established:

- Focus on staff flows
- Focus on supplier collaboration and purchasing
- Focus on outsourcing
- Focus on route optimization and optimal allocation of resources
- Focus on forecasting and scheduling
- Focusing on home healthcare and telemedicine

Stage 2: Conducting the literature review

A comprehensive literature search was conducted, which was then narrowed down to a list of core contributions to address the RQs (Denyer and Tranfield, 2009). A search string with the keywords from Table 1 was applied in two research databases using a Boolean search string with an 'OR' operator connecting the keywords within each group of keywords in Table 1. The 'AND' operator connected groups I to IV, and the 'NOT' operator connected the group of excluding keywords. The search string was entered into the following research databases:

- EBSCOhost research database
- SCOPUS research database

The two databases were chosen because they both cover journals focusing on logistics, SCM and management in healthcare. Searching the two databases with the search string from Table 1 resulted in 533 hits in the EBSCO database and 1,335 hits in the SCOPUS database with the search limited to English language peer-reviewed papers published between 1990 and 31 July 2016. The progress of narrowing the search results to a relevant set of manageable papers is illustrated in Figure 1. At each step of the paper selection process, papers were included or excluded based on selection criteria. From the database search, 39 papers were included in the final review. From these 39 papers, an additional 42 papers were derived from the reference lists and added to the final paper selection. In total, 81 papers were selected for the final literature study. Although the initial search only included peer reviewed papers, some 'grey literature', i.e. not peer-reviewed, was included in the final study because of the contribution regarding current practice in healthcare logistics. The application of different methods for literature search and the inclusion of different types of publications can be expected for systematic reviews (Denyer and Tranfield, 2009).

A data extraction form was employed to reduce human error and bias (Tranfield et al., 2003). The form included information on details for reference, method, initial categorization of themes, investigated process types, SC focus, and country setting. For analyzing the papers, a realist synthesis approach was adopted as suggested by Denyer and Tranfield, where context, intervention, mechanism and outcome are determined (Denyer and Tranfield, 2009). I.e. the realist synthesis approach is explanatory in nature (Rousseau et al., 2008), which is reflected in the RQs. The context constitutes the healthcare logistics environment and the contingent factors (RQ2), which are closely related to the evidence evaluation criterion 'intervention compliance' (Rousseau et al., 2008). The interventions are the investigated interventions and approaches for improving healthcare logistics (RQ1), and the mechanisms provide the link to the outcome, i.e. improved healthcare logistics performance.

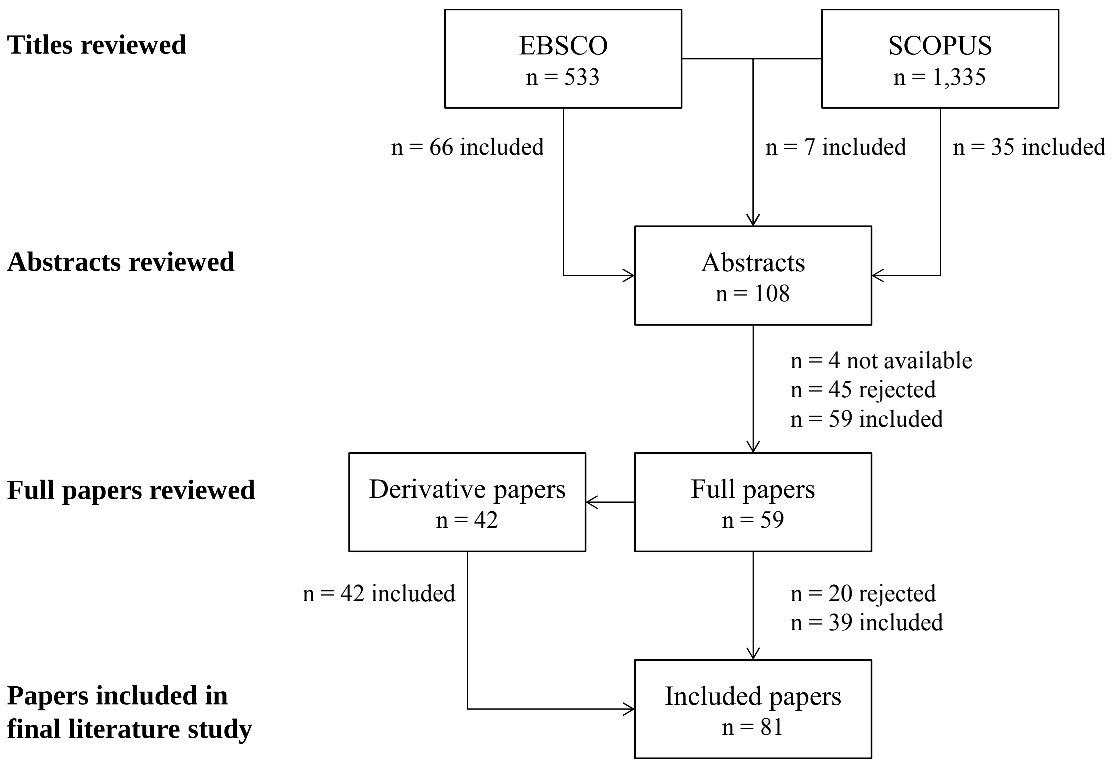

Figure 1. Paper selection process

Stage 3: Reporting and dissemination

Systematic literature reviews report the evidence from literature to conclude on what is known and not known about a RQ (Denyer and Tranfield, 2009). In this stage, a descriptive analysis of the field is provided followed by a thematic analysis (Tranfield et al., 2003). The descriptive analysis considers the following aspects: publication year, location of study, journals, methods, scientific vs. grey literature, and SC focus of the study. A thematic analysis is then provided to enfold what is known about the research field. Based on the descriptive and thematic analyses, a research agenda is proposed.

Descriptive analysis

The distribution of included papers according to year of publication can be seen in Figure 2. The figure shows that the reviewed literature on healthcare logistics appeared first in 1992, has increased over the years, but remains scarce and suggests a recent decline.

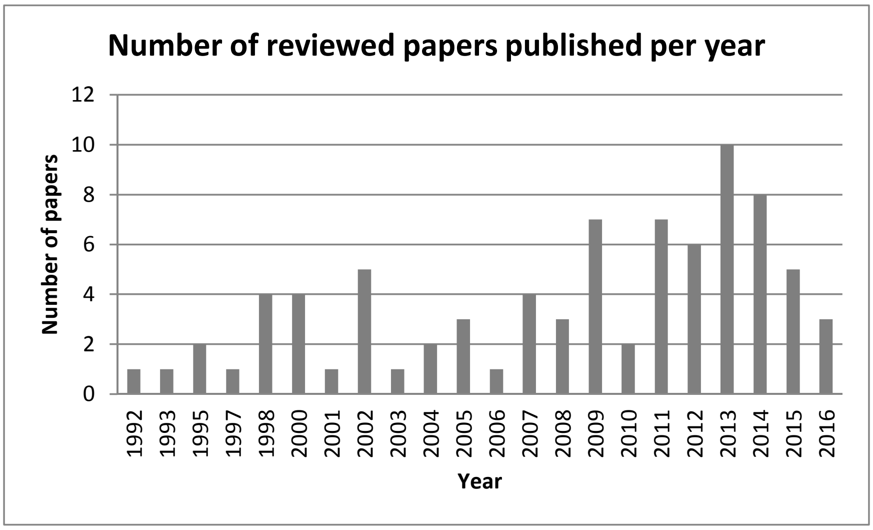

Figure 2. Papers included in review according to year of publication

Table 2 includes an overview of where the studies were conducted, i.e. not the affiliation of authors. Most studies were conducted in North America, closely followed by Europe. In addition, Table 2 provides an overview of applied methods, showing that the case study method is the most prevalent method. Case studies are applicable to exploratory studies (Yin, 1994), indicating that healthcare logistics is a relatively undeveloped research field. Five of the papers are of a descriptive nature and do not specify a method. Most papers are of a qualitative nature, i.e. 43 papers (52%), 27 papers (33%) are quantitative and 11 papers (14%) are a mix of both.

Papers from 60 different journals are included in the literature review. Only 13 journals have more than one paper included in the study, contributing with 42% of the reviewed papers. The top four journals are *Supply Chain Management: An International Journal* with six papers, *Transfusion* with four papers, *Production Planning and Control* with three papers, and *Healthcare Financial Management* with three papers. Together, these four journals contribute with 20% of the reviewed papers. Nine of the reviewed papers (11%) are considered grey literature, and 72 of the papers are from peer-reviewed journals (89%). The distribution of papers across several journals together with the share of grey literature support the conclusion that healthcare logistics is an immature research field.

Table 2. Geographical and methodological distribution of papers

Paper details	No. of papers	Percentage
Region where study was conducted		
North America	28	35%
Europe	25	31%
N/A	13	16%
Asia	6	7%
Multiple regions	6	7%
Australasia	2	2%
Africa	1	1%
Applied method		
Case study	42	52%
Survey	13	16%
Mathematical modelling	5	6%
Descriptive	5	6%
Simulation	4	5%
Literature review	4	5%
Mix of methods	3	4%
Editorial	2	2%
Discussion	1	1%
Diagnostic investigation	1	1%
Action Research	1	1%

The focus of the reviewed papers differs between the internal SC, the immediate SC, i.e. first tier collaborators, and the entire SC. Of the reviewed papers, 38 papers (47%) focus on the internal SC, 30 papers (37%) focus on the immediate SC, and 13 papers (16%) focus on the entire SC.

Thematic analysis

The second part of the systematic review consists of a thematic analysis. Analysis of the papers revealed four types of interventions for improving processes: 1) process interventions, i.e. business process management (BPM), 2) logistics and SCM interventions, 3) technological interventions, and 4) organizational interventions. The thematic analysis is structured according to these four themes. For the purpose of this study, BPM is defined as a structured approach to analyze and continually improve fundamental activities in a company (Zairi, 1997). The four identified themes are in accordance with extant literature. E.g. the importance of processes, technologies and organizational development to improve the SC has been demonstrated by Mohanty and Deshmukh (Mohanty and Deshmukh, 2000) and specifically for healthcare logistics (Feibert and Jacobsen, 2015; Jørgensen et al., 2012). Furthermore, several authors have acknowledged the importance of fit between an organization's strategy and the technology, organization, processes and environment (Davenport, 1993; Hammer and Champy, 1993; Hung, 2006; Kanellis et al., 1999; Leavitt, 1965).

BPM

A more process oriented system can lead to better utilization of resources (Kumar et al., 2008). This section of the paper focuses on how logistics processes are managed in hospitals and is structured as follows. First, healthcare logistics processes are characterized. Second, the BPM approaches applied to healthcare logistics processes are identified. Table 3 summarizes the identified sub-themes.

Process characteristics. Hospital materials flows include items such as pharmaceutical products (Beier, 1995; Gebicki et al., 2014), blood products (Hemmelmayr et al., 2009; Rautonen, 2007), sterile supplies (Fredendall et al., 2009), medical supplies (de Vries, 2011), closed-loop supplies, e.g. linen (Kumar and Rahman, 2014), medical equipment (Fredendall et al., 2009), and apparel (Chan et al., 2012). Such healthcare supplies can be divided into ordinary products, i.e. often used and inexpensive, and special product, i.e. rarely used and often expensive (Persona et al., 2008). In addition, Granlund and Wiktorsson mention the transport of waste, materials, laundry, food, samples, paper, mail, money, and patients (Granlund and Wiktorsson, 2013). Thus, transport enables the flow of materials in hospitals (Yau et al., 1998). In addition to the forward flow of goods, hospitals should consider the reverse SC as an opportunity for improvement (Ritchie et al., 2000).

Healthcare SCs in general are considered complex (Böhme et al., 2013), and logistics activities are often fragmented processes performed across several departments (Landry and Philippe, 2004). Processes tend to be paper based, manual processes characterized by a lack of data, traceability, and visibility (Anand and Wamba, 2013). Processes are therefore typically subject to variations in processing times (Anand and Wamba, 2013), unpredictable demand and unpredictable capacity, leading to inefficient logistics processes (Anand and Wamba, 2013; Yau et al., 1998) that are difficult to schedule (Jarrett, 1998). Hospitals should aim to achieve seamless coordination to enhance patient care delivery (Yau et al., 1998), but the complexity of healthcare SCs can make it difficult to understand why operational failures occur and how they affect productivity (Fredendall et al., 2009). Moreover, medical supplies tend to be overstocked to avoid stock-outs that could have serious and potentially fatal consequences for patients. Overstocking leads to increased costs, and finding the right balance between quality and costs is therefore one of the main logistical challenges for hospitals (de Vries, 2011).

Pharmaceutical products constitute the most investigated flow in healthcare logistics. Previous research has focused on the entire pharmaceutical SC rather than internal logistics for hospital pharmacies (Romero and Lefebvre, 2015). The pharmaceutical SC is characterized by a complex network of physicians, pharmacies, hospitals, wholesalers, and government organizations. Medicine safety and security considerations adds to SC complexity (Chircu et al., 2014). Furthermore, there is a large variety of pharmaceutical items with differences in criticality (Beier, 1995). Some products may require special handling, e.g. temperature control (Beier, 1995), and consequently separate storage from other products (Pan and Pokharel, 2007). Moreover, pharmaceutical SCs often lack control and accountability for drugs within the hospital (Thomas et al., 2000).

In addition to a complex environment, pharmaceutical SCs operate under high levels of uncertainty caused by process immaturity and poor inter-functional integration (Böhme et al., 2016). Issues related to availability from the supplier and product perishability add to this uncertainty (Gebicki et al., 2014). Due to the serious effects of stock-outs, hospitals often carry excess stock. However, excess stock and product perishability increases the likelihood of waste, which is particularly costly for expensive drugs (Ritchie et al., 2000).

Blood product flow is the second most investigated process. Blood products are characterized by unpredictable demand and short shelf life of down to five days (Fontaine et al., 2009; Gomez et al., 2015; Hemmelmayr et al., 2009; Rautonen, 2007), although variability in demand may only pose a problem during holiday season (Spens and Bask, 2002). The main drivers for improving the blood SC are cost efficiency of the internal and external SC, reliability of blood deliveries, and matching supply with demand (Rautonen, 2007). Due to the nature and purpose of blood products, the most common performance measures considered in research relate to outdates, shortages and availability. In practice, however, quality is the most important factor (Beliën and Forcé, 2012). For an extensive literature review on blood SCM, the authors refer to the 2012 paper by Beliën and Forcé (Beliën and Forcé, 2012).

Sterile supplies such as surgical instruments are a direct part of patient treatment and directly affect the quality of care. Some of the problems identified in the supply of surgical tools are interruptions in the sterilization process leading to dirty or missing instruments, difficulties in distinguishing between instrument sets and identifying faulty instruments, wrongful placement of supplies and equipment, and low capacity at bottlenecks (Fredendall et al., 2009).

BPM approaches. The following BPM approaches were identified in literature: 1) business process reengineering (BPR), 2) cellular operations 3) performance measurement, 4) benchmarking, and 5) process standardization. All the identified BPM approaches were found to be applicable to healthcare logistics processes and to improve process performance. Each will be discussed briefly in the following.

Despite the complexity and uncertainty characterizing the healthcare environment, Kumar and colleagues argue that BPR is suitable for a healthcare environment because of repetitive tasks, high volumes and tangible items (Kumar et al., 2008).

Cellular operations are suggested by Parnaby and Towill to improve hospital logistics processes by minimizing the number of handovers and delays. They argue that hospital systems should be decomposed into work cells that provide narrowly focused services (Parnaby and Towill, 2009).

Performance measurement can help ensure improved process performance, e.g. of the reverse logistics process (Ritchie et al., 2000). However, there is no consistent way of measuring SC performance in healthcare, which makes it difficult to implement and assess the success of a change (McKone-Sweet et al., 2005).

Benchmarking is a BPM approach closely related to performance measurement, allowing for comparison of performance metrics and best practices. A benchmarking study of Australasian pharmaceutical SCs shows that the highest achieving SC performs far below the average European automotive SC (Böhme et al., 2016). Some methodological challenges have been identified for benchmarking public hospital SCs (Böhme et al., 2013):

- Inconsistency and lack of meaningful process information
- Political agendas and political motivation
- The complexity of healthcare systems

The final BPM approach considered here is process standardization. Standardization can ensure the efficiency and effectiveness of processes (Ritchie et al., 2000). Furthermore, standard operating procedures (SOPs) can act as a coordinating mechanism and prevent quality issues (Fredendall et al., 2009).

Table 3 lists the reviewed literature contributing to each sub-theme related to BPM in healthcare logistics. The table reveals that limited literature characterizes specific process types. The analysis shows that pharmaceutical, blood and sterile products have received most attention in terms of process characterization. These results are in accordance with Kriegel et al. who found that logistics activities relating to acute medical, patient-focused, and cost-intensive domains are of main interest to decision makers (Kriegel et al., 2013).

The application of BPM approaches has scarcely been reported for healthcare logistics processes. Similarly, the literature review by Dobrzykowski et al. found that the design and measurement of services in healthcare remains one of the least investigated topics in healthcare SCM (Dobrzykowski et al., 2014). The BPM approaches that appeared most often in the reviewed literature are performance measurement, benchmarking, and process standardization. Finally, apart from the BPR paper, literature does not indicate under which circumstances to apply the different BPM approaches. In conclusion, process characterization, application of BPM approaches and contingent factors determining when to apply BPM approaches provide opportunities for future research.

Logistics and SCM interventions

As mentioned in the Introduction, logistics management is a subset of SCM and includes management of the forward and reverse flow and storage of goods (Council of Supply Chain Management Professionals, 2016). Thus, inventories constitute part of logistics activities in a hospital. The inventories are replenished through an inbound flow of goods from external suppliers. Hence, the replenishment of hospital supplies is a constituent part of logistics management in a hospital. According to de Vries, the physical infrastructure of inventory systems considers 1) whether a stockless scheme should be applied and 2) the way planned and emergency orders are dealt with (de Vries, 2011). These two aspects are here referred to under the umbrella term 'replenishment systems', i.e. the manner in which inventories are replenished. The following five sub-themes relating to replenishment systems were identified in literature: 1) replenishment policy, 2) just-in-time (JIT), 3) stockless systems, 4) vendor managed inventory (VMI), and 5) single dose system. In addition, three SC design themes were identified: 1) SC integration, 2) logistics and SC innovation, and 3) responsive SCs. Contingent factors for selecting replenishment systems are stated in Table 4. Corresponding factors were not identified for the SC design sub-themes.

Replenishment policy. Stock-outs can have severe consequences for patients, and hospitals must therefore consider criticality levels and consequences of stock-outs when developing replenishment policies (Gebicki et al., 2014; Perera et al., 2009). The short shelf-life of blood products increases the risk of stock-outs (Stanger et al., 2012), but also the risk of waste due to supply and demand uncertainty (Fontaine et al., 2009). Thus, for critical products, there is a trade-off between costs and patient safety (Gebicki et al., 2014). Applying target stock levels and order patterns is considered best practice (Stanger et al., 2012). To deal with planned and emergency orders, a study of hospitals in Singapore identified the use of periodic review and replenishment and ad hoc orders (Pan and Pokharel, 2007). However, Landry & Philippe argue that the use of a two-bin replenishment system is recommendable to a par level, i.e. "order-up-to" level, system (Landry and Philippe, 2004).

Table 3. Overview of themes and references to literature

Identified themes			Identified literature	No. of papers
BPM	*Characteristics*	Non-specific items	(Anand and Wamba, 2013; Böhme et al., 2013; Fredendall et al., 2009; Granlund and Wiktorsson, 2013; Jarrett, 1998; Kumar and Rahman, 2014; Landry and Philippe, 2004; Persona et al., 2008; Ritchie et al., 2000; de Vries, 2011; Yau et al., 1998)	11
		Pharmaceuticals	(Beier, 1995; Böhme et al., 2013, 2016; Chircu et al., 2014; Gebicki et al., 2014; Pan and Pokharel, 2007; Ritchie et al., 2000; Romero and Lefebvre, 2015; Thomas et al., 2000)	9
		Blood products	(Beliën and Forcé, 2012; Fontaine et al., 2009; Gomez et al., 2015; Hemmelmayr et al., 2009; Rautonen, 2007; Spens and Bask, 2002)	6
		Sterile supplies	(Fredendall et al., 2009)	1
	Approach	BPR	(Kumar et al., 2008)	1
		Cellular operations	(Parnaby and Towill, 2009)	1
		Perf. measurement	(Beliën and Forcé, 2012; Böhme et al., 2013, 2016; Lega et al., 2012; McKone-Sweet et al., 2005; Ritchie et al., 2000; Swinehart and Smith, 2005)	7
		Benchmarking	(Aptel and Pourjalali, 2001; Böhme et al., 2013, 2016; Dacosta-Claro, 2002; Hastreiter et al., 2013; Landry and Philippe, 2004; Longo and Masella, 2002; Marino, 1998; Poulin, 2003)	9
		Process std.	(Fontaine et al., 2009; Fredendall et al., 2009; Perera et al., 2009; Ritchie et al., 2000; Stanger et al., 2012)	5
Logistics and SCM interventions	*Replenishment systems*	Replenishment policy	(Aptel and Pourjalali, 2001; Beier, 1995; Böhme et al., 2013, 2016; Çakici et al., 2011; Callender and Grasman, 2010; Fontaine et al., 2009; Gebicki et al., 2014; Gomez et al., 2015; Landry and Philippe, 2004; Marino, 1998; Nicholson et al., 2004; Pan and Pokharel, 2007; Perera et al., 2009; Rautonen, 2007; Rosales et al., 2014; Stanger et al., 2012; de Vries, 2011; Wang et al., 2015; Yau et al., 1998)	19
		JIT	(Aptel and Pourjalali, 2001; Heinbuch, 1995; Jarrett, 1998; Kim and Schniederjans, 1993; Van de Klundert et al., 2008; Kumar et al., 2008; Marino, 1998; Mustaffa and Potter, 2009; Pan and Pokharel, 2007; Persona et al., 2008; Whitson, 1997; Wilson et al., 1992)	12
		Stockless system	(Danas et al., 2002; Kim and Schniederjans, 1993; Kumar et al., 2008; Landry and Philippe, 2004; Marino, 1998; Mustaffa and Potter, 2009; Rivard-Royer et al., 2002; de Vries, 2011; Wilson et al., 1992)	9
		VMI	(Aptel and Pourjalali, 2001; Guimarães et al., 2013; Hemmelmayr et al., 2009; Haavik, 2000; Kim and Schniederjans, 1993; Mustaffa and Potter, 2009; Pan and Pokharel, 2007)	7
		Single dose	(Granlund and Wiktorsson, 2013; Pinna et al., 2015)	2
	SC design	SC integration	(Aptel and Pourjalali, 2001; Bailey et al., 2013; Breen and Crawford, 2005; Brennan, 1998; Böhme et al., 2013, 2016; Chen et al., 2013; Elleuch et al., 2014; Gebicki et al., 2014; Landry and Philippe, 2004; Mustaffa and Potter, 2009; Nicholson et al., 2004; Pan and Pokharel, 2007; Rivard-Royer et al., 2002; Su et al., 2011; de Vries and Huijsman, 2011; Wilson et al., 1992)	17
		SC/logistics innov.	(Kumar et al., 2008; Lee et al., 2011; Lega et al., 2012; Spens and Bask, 2002; Su et al., 2011)	5
		Responsive SCs	(Callender and Grasman, 2010)	1
Technological interventions		Aut. transport	(Bloss, 2011; Böhme et al., 2016; Granlund and Wiktorsson, 2013; Jørgensen et al., 2013; Kumar and Rahman, 2014; Landry and Philippe, 2004; Yau et al., 1998)	7
		Aut.storage/retriev.	(Bailey et al., 2013; Bourcier et al., 2016; Böhme et al., 2016; Granlund and Wiktorsson, 2013; Landry and Philippe, 2004; Rosales et al., 2014)	6
		Barcodes	(Beier, 1995; Böhme et al., 2013, 2016; Çakici et al., 2011; Chan et al., 2012; Danas et al., 2002; Granlund and Wiktorsson, 2013; Maviglia et al., 2007; Romero and Lefebvre, 2015; Yao et al., 2012; Yau et al., 1998)	11
		RFID	(Anand and Wamba, 2013; Bendavid et al., 2010, 2012; Çakici et al., 2011; Chan et al., 2012; Chircu et al., 2014; Coustasse et al., 2013; Van de Klundert et al., 2008; Kumar and Rahman, 2014; Lee et al., 2011; Romero and Lefebvre, 2015; Wicks et al., 2006; Wieser, 2011; Xie et al., 2016; Yao et al., 2012; Yazici, 2014)	16
		ICTs	(Aptel and Pourjalali, 2001; Beier, 1995; Breen and Crawford, 2005; Böhme et al., 2016; Callender and Grasman, 2010; Chen et al., 2013; Dunbar, 2015; Gomez et al., 2015; Kumar et al., 2008; Lee et al., 2011; Maviglia et al., 2007; Pan and Pokharel, 2007; Perera et al., 2009; Rautonen, 2007; Su et al., 2011; de Vries, 2011; Xie et al., 2016; Yau et al., 1998)	18
Organizat. interventions		Org. log. activ.	(Aptel et al., 2009; Aptel and Pourjalali, 2001; Bloss, 2011; Landry and Philippe, 2004; Pan and Pokharel, 2007)	5
		HRM	(Callender and Grasman, 2010; Landry and Philippe, 2004; Stanger et al., 2012)	3
		Centralization / decentralization	(Al-Shaqha and Zairi, 2000; Aptel and Pourjalali, 2001; Callender and Grasman, 2010; Engelund et al., 2007; Kumar et al., 2008; Landry and Philippe, 2004; Lega et al., 2012; Longo and Masella, 2002; Stanger et al., 2012; Thomas et al., 2000; de Vries, 2011; Yau et al., 1998)	11
		Org./social setting	(Aptel and Pourjalali, 2001; Böhme et al., 2016; Callender and Grasman, 2010; Landry and Philippe, 2004; McKone-Sweet et al., 2005; Ritchie et al., 2000; de Vries, 2011; Wieser, 2011)	8

Table 4. Factors impacting the choice of intervention

Contingent factors	Relation of factors to intervention	SCM and logistics interventions					Technological interventions			
		RP	***JIT***	***SLS***	***VMI***	***SD***	***AT***	***ASR***	***BC***	***RFID***
Demand variability	Replenishment model should take demand variability into account (Wang et al., 2015). Demand variability affects safety stock (Aptel and Pourjalali, 2001; Beier, 1995). Apply EOQ to reduce stock levels (Beier, 1995). Combine stockless with virtual pharmacy to cope with unexpected demand (Danas et al., 2002).	X		X						
Supply variability	Develop contingency plan in conjunction with JIT to avoid SC disruptions (Jarrett, 1998).		X							
Product criticality	Consider product criticality when developing a RP (Gebicki et al., 2014; Perera et al., 2009)	X								
Consequences of stock-outs	Consider consequences of stock-outs when developing a replenishment policy (Gebicki et al., 2014; Perera et al., 2009)	X								
Shelf-life / perishability	RP depends on shelf-life (Pan and Pokharel, 2007)	X								
Service level	Inventories are a balance of ordering costs, carrying costs and service levels and safety stocks may be necessary for high service levels (Gebicki et al., 2014). Consider the effect on quality of service (Pinna et al., 2015).	X								
Safety	Consider safety effects of any system (Pinna et al., 2015).	X	X	X	X	X				
Total cost of a system	Total costs of a system should be considered rather than short term gains (Marino, 1998). Consider costs vs. financial benefits (Pinna et al., 2015). Inventories are a balance of ordering costs, carrying costs and service levels (Gebicki et al., 2014).	X	X	X	X	X				
Monetary value	JIT not recommended for low value items (Jarrett, 1998). JIT is inefficient for special products, i.e. rarely used and often expensive (Persona et al., 2008).		X							
Product volume	RP depends on the quantity (Pan and Pokharel, 2007). JIT recommended for high volume items (Jarrett, 1998; Whitson, 1997). Stockless systems usually used for small product categories (Kim and Schniederjans, 1993).	X	X	X						
Frequency of product use	Stockless is usually used for small product categories and frequently used items (Kim and Schniederjans, 1993). JIT is inefficient for special products, i.e. rarely used and often expensive (Persona et al., 2008).		X	X						
Repetition	Repetitive tasks makes materials handling in healthcare suitable for JIT (Whitson, 1997).		X							
Tangibility	Tangibility makes materials handling in healthcare suitable for JIT (Whitson, 1997).		X							
Product bulkiness	RP depends on product bulkiness (Pan and Pokharel, 2007).	X								
Inventory level and mix	Inventory level and mix concerns the RP, and cost effects should be considered for any system (Marino, 1998).	X	X	X	X	X				
Ordering patterns	Ordering patterns concerns the RP, and cost effects should be considered for any system (Marino, 1998).	X	X	X	X	X				
Supplier proximity	JIT and stockless unsuitable for long distances and isolation (Van de Klundert et al., 2008; Kumar et al., 2008; Mustaffa and		X	X	X	X				

and accessibility	Potter, 2009; Pan and Pokharel, 2007; Wilson et al., 1992). VMI solutions suitable where suppliers are close (Pan and Pokharel, 2007). Others argue it is suitable for remote areas (Mustaffa and Potter, 2009). Distance and the cost effect should be considered for any system (Marino, 1998).									
Use of e-commerce/ IT capabilities	The use of e-commerce makes the implementation of JIT and VMI easier (Marino, 1998; Pan and Pokharel, 2007). RFID most beneficial in combination with continuous replenishment (Çakici et al., 2011).	X	X		X					
Distributor's ability to support in planning/forecasting	The cost effect of the distributor's ability to support in planning and forecasting should be considered for any system (Marino, 1998).		X	X	X	X				
Willingness to change	The cost effect of the willingness to change should be considered for any system (Marino, 1998).		X	X	X	X				
Load capacity	Load capacity influences what type of technology is suitable for transporting specific items (Landry and Philippe, 2004).						X			
Time-criticality	The delivery of certain product types is time-critical and may require speedy delivery at all times of the day (Bailey et al., 2013). Average waiting time may influence choice of technology – pneumatic tube system found to perform better than AGV solution for transporting blood samples (Jørgensen et al., 2013).						X	X		
Level of process automation	Automatic counting and reordering achieved through RFID compared to barcodes (Çakici et al., 2011).								X	X
Frequency of use	The number of times barcodes are used affects the financial viability of the solution (Maviglia et al., 2007).								X	
Efficiency of technology	Simultaneous and multiple reads with possible with RFID, but not barcodes (Çakici et al., 2011).								X	X
Data capacity	Higher data capacity for RFIDs than barcodes (Çakici et al., 2011).								X	X
Line of sight requirement	Depending on the process, line of sight to scan an object may or may not be required. RFIDs require no line of sight, barcodes do (Anand and Wamba, 2013; Kumar and Rahman, 2014).								X	X
Data encryption	The level of data encryption is better for RFIDs than barcodes (Çakici et al., 2011; Coustasse et al., 2013).								X	X
Read range capabilities	RFIDs can be read at longer distances than barcodes (Anand and Wamba, 2013).								X	X
Need for real-time tracking	RFIDs enable real-time tracking of items, barcodes do not (Anand and Wamba, 2013; Çakici et al., 2011).								X	X
Durability	Barcodes and RFID tags are exposed to the environment and may wear and tear. RFIDs are more durable than barcodes (Anand and Wamba, 2013; Çakici et al., 2011).								X	X
Stock-taking costs vs. data accuracy	The ratio between stock-taking costs and inventory accuracy determines whether a barcoding or RFID-system outperforms the other (Chan et al., 2012).								X	X
The network effect	The decision to use RFID or barcodes may depend on what everyone else uses (Çakici et al., 2011; Romero and Lefebvre, 2015).								X	X

JIT. Different inventory management systems can reduce the high inventory costs experienced in hospitals. In a JIT solution, deliveries from the supplier occur 3-7 times a week (Kim and Schniederjans, 1993; Kumar et al., 2008; Whitson, 1997). The distributor acts as the hospital's warehouse and delivers supplies in bulks, which the hospital then breaks down and delivers per department (Kim and Schniederjans, 1993; Marino, 1998).

Stockless system. In a stockless solution, the supplier breaks each delivery down to the smallest units customized according to a requisition or cart exchange scheme, practically eliminating the hospital's storage room and inventory (Kim and Schniederjans, 1993; Marino, 1998). Although this is the common view, Whitson views such a solution as a true JIT solution (Whitson, 1997). Thus, there seems to be some disagreement on what constitutes as JIT and stockless solutions in healthcare.

A JIT system is not necessarily stockless and a stockless system is not necessarily JIT (Kim and Schniederjans, 1993; Marino, 1998), but the two systems often go hand in hand (Marino, 1998). Both JIT and stockless systems can improve the effectiveness of a hospital's material handling compared to a conventional system, but neither have been found to outperform the other (Kim and Schniederjans, 1993). However, the substantial work involved for distributors in stockless systems meant that the popularity of stockless systems experienced throughout the 1980's had faded by the late 1990's. The 1998 paper by Marino with the telling title 'The stockless craze: Is it finally over?' strongly alludes to the stockless development (Marino, 1998). Accordingly, the reviewed papers investigating JIT or stockless systems were published in the 1990's or early 2000's.

VMI. VMI is a delivery strategy that shifts the replenishment decision from the buyer to the supplier. Deliveries may be as infrequent as once a week, but the strategy enables a demand-driven SC by allowing suppliers to respond to a hospital's immediate supply needs based on the hospital's consumption data (Haavik, 2000). An example of applied VMI in healthcare is the blood SC, where VMI was found to significantly reduce the delivery costs for the supplier (Hemmelmayr et al., 2009).

Aptel and Pourjalali distinguish between three types of distribution from suppliers to hospitals: 1) delivery to medical departments via a central hospital inventory, 2) semi-direct delivery via a medical department inventory, and 3) direct delivery via daily replenishment to a small medical department inventory (Aptel and Pourjalali, 2001). The first option is similar to a conventional inventory system (Kim and Schniederjans, 1993). The second option seems similar to JIT as described earlier, although the authors describe the third option as similar to JIT. Yet, the description of the third option shares a strong resemblance to VMI. Once again, there is some disagreement on definitions, in this case for JIT and VMI.

Single dose system. Pinna and colleagues investigate a single dose pharmaceutical SC and find that benefits include ward stock reductions, inventory reductions, reduced medicine cabinet management, reduction in likelihood of errors, and simplification of the overall process of ward cart preparation and medicine administration (Pinna et al., 2015). An automated storage and retrieval system can enable such a single dose system (Granlund and Wiktorsson, 2013).

Different replenishment systems are valid under different circumstances (Marino, 1998). Table 4 summarizes the identified contingent factors that affect the choice of replenishment system. The right hand side indicates which replenishment systems are affected by the contingent factors. The replenishment systems not already abbreviated are denoted as follows: replenishment policy (RP), stockless system (SLS), and single dose (SD). The table does not include SC integration or logistics and SC innovation as literature does not in the same way prescribe when these concepts are applicable.

SC integration. Healthcare SCs are characterized by an internal and external SC (Pan and Pokharel, 2007; Rivard-Royer et al., 2002). Inter-functional integration is a driver of good healthcare SC performance (Böhme et al., 2016), and integrating the internal SC in hospitals will lead to efficiencies of logistics activities (Landry and Philippe, 2004). Similarly, the interface to the external SC provides opportunities for improvement. In general, duplicate activities in the SC is an issue (Landry and Philippe, 2004), and streamlining and standardizing disjointed SC activities whilst sharing common processes across SC partners ensures the best placement of a service in the SC (Brennan, 1998).

Logistics and SC innovation. Lega et al. identified SC centralization as a SC innovation that can lead to improved SC efficiency (Lega et al., 2012). Similarly, Lee and colleagues found that SC innovation positively affects SC efficiency, supplier cooperation and quality management practices, ultimately leading to improved organizational performance (Lee et al., 2011). Furthermore, logistics innovation can improve SC relations, learning between parties, and financial results (Su et al., 2011). In addition, logistics innovation combined with collaboration may be preferable to outsourcing as it ensures process control (Su et al., 2011). Finally, Spens and Bask provide a framework for improving the healthcare SC that considers three aspects: 1) SC structure, 2) types of business process links, and 3) management components (Spens and Bask, 2002).

Responsive SCs. To address the uncertainty of demand in healthcare SCs, Callender and Grasman argue that a responsive SC may be preferable to a cost efficient SC. They contend that a responsive SC does not necessarily translate into high inventory levels (Callender and Grasman, 2010).

Overall, replenishment systems are the most researched logistics and SC themes, mainly focusing on replenishment policies and the application of JIT and stockless systems. For

SC design, SC integration has been researched the most. The provided overview of literature in Table 3 indicates that there is room for more research, particularly on logistics and SC innovation, responsive SCs, and replenishment systems alternative to JIT and stockless. Finally, logistics and SCM concepts not covered by existing literature are potential avenues of future research.

Technological interventions

Healthcare logistics processes are often characterized by a low degree of automation (Landry and Philippe, 2004). Supporting information systems and supply infrastructure can be drivers of good healthcare SC performance (Böhme et al., 2016). However, the implementation of technologies does not necessarily solve efficiency issues and should only be implemented where appropriate (Yau et al., 1998). The different applications of technologies in healthcare logistics are presented in the following.

Automated transport. The use of technologies can improve transport logistics in hospitals (Yau et al., 1998). Best practice technologies include integrated transport systems (Landry and Philippe, 2004), pneumatic tubes, robotics (Landry and Philippe, 2004; Yau et al., 1998), and automated guided vehicles (AGVs) (Böhme et al., 2016; Landry and Philippe, 2004). Pneumatic tube systems are typically used for transporting blood, medicine, paper, money, and samples (Granlund and Wiktorsson, 2013), where AGVs have been used for transporting items such as food, linen, laundry, waste, medical equipment, lab results, and medicine (Bloss, 2011; Granlund and Wiktorsson, 2013; Kumar and Rahman, 2014). Jørgensen et al. compare AGVs and a pneumatic tube system for transporting blood samples and found that a pneumatic tube solution would perform better in terms of average waiting time (Jørgensen et al., 2013).

Automated storage and retrieval. Several authors consider the use of automated pharmaceutical dispensing machines as a best practice that is often combined with a central hospital pharmacy (Bourcier et al., 2016; Böhme et al., 2016; Landry and Philippe, 2004). Such automated dispensing machines can also be used for other types of products, e.g. medical devices (Bourcier et al., 2016). Another option is for hospitals to apply a centralized automated storage and retrieval system, e.g. for single doses of medicine (Granlund and Wiktorsson, 2013). Bailey et al. suggest the use of a secure electronic locker box for time-critical products to enable deliveries at all hours of the day to a central city location (Bailey et al., 2013).

Barcodes. Barcodes can provide track and trace data and is another technology considered best practice in healthcare logistics (Beier, 1995; Böhme et al., 2013, 2016; Yau et al., 1998). Barcodes are often used when dispensing pharmaceutical products to patients (Granlund and Wiktorsson, 2013), which reduces medication dispensing errors (Maviglia et al., 2007).

RFID. Like barcodes, RFID technology can provide track and trace information (Anand and Wamba, 2013; Chircu et al., 2014; Yao et al., 2012). The use of RFID in hospitals mainly relates to tracking medication, equipment, staff and patients (Anand and Wamba, 2013; Coustasse et al., 2013; Kumar and Rahman, 2014; Yazici, 2014). RFIDs can be used for identification and verification, sensing, e.g. temperatures (Yao et al., 2012), workflow management, SCM (Bendavid et al., 2010; Kumar and Rahman, 2014), automatic data capturing, triggering actions such as automatic replenishment (Bendavid et al., 2010, 2012; Kumar and Rahman, 2014; Yao et al., 2012), maintenance management (Bendavid et al., 2010; Xie et al., 2016), and improved asset management (Coustasse et al., 2013; Xie et al., 2016).

RFID solutions are more costly to implement and maintain than barcodes (Çakici et al., 2011; Romero and Lefebvre, 2015), but perform better in terms of efficiency and accuracy, inventory visibility, inventory costs, readiness of purchase order, labor costs, patient security, cycle times, waste management, and reverse logistics (Romero and Lefebvre, 2015). Despite the significant benefits of RFID over barcoding, RFID does not necessarily outperform barcodes (Chan et al., 2012). Table 4 includes a comparison of the attributes of RFID and barcoding.

Information and communication technologies (ICTs). The deployment of ICTs in healthcare SCs is closely related to the coordination and integration of processes. ICTs can significantly improve logistics activities such as inventory management (de Vries, 2011). Thus, the use of replenishment systems is considered best practice (Beier, 1995; Böhme et al., 2016; Yau et al., 1998). Furthermore, EDI allows for electronic ordering of goods and transfer of funds through a secure line between the supplier and hospital (Breen and Crawford, 2005). Hence, ICTs can enable hospital-supplier integration (Chen et al., 2013). In addition to the technologies already covered in this section, ICTs in healthcare logistics include ERP systems (Lee et al., 2011; Pan and Pokharel, 2007), e-clinical systems, e-SCM systems, e-asset systems (Xie et al., 2016), and PDAs (Pan and Pokharel, 2007).

Literature is scarce in terms of advising under which circumstances to implement different technologies and more research is needed on this topic. Table 4 provides an initial list of factors impacting the decision to choose between different technologies. The table indicates for which type of technology the factor is relevant according to literature, i.e. automated transport (AT), automated storage and retrieval (ASR), barcodes (BC), and RFID. No factors were identified specifically for ICTs.

Table 3 provides an overview of the identified literature pertaining to technological interventions in healthcare logistics. The most investigated type of technology is ICTs, which is also the broadest category. RFID technology has received almost as much attention in literature despite being a much newer technology and a narrower category.

Organizational interventions

The final main theme in healthcare logistics literature is the organizational aspect. The following four sub-themes were identified: 1) the organization of logistics activities, 2) human resource management (HRM), 3) a centralized vs. decentralized organization, and 4) the organizational setting in which logistics processes are embedded. Each sub-theme is discussed in the following.

Organization of logistics activities. Activities performed by the logistics and materials management departments in hospitals include purchasing, physical supply, receiving, inventory management, internal physical and service distribution, transport, supplier management, and management of information systems (Aptel et al., 2009; Pan and Pokharel, 2007). Some logistics departments handle services such as telecommunications, facilities management, maintenance, engineering services, telemedicine, home care services, food services, laundry services, linen services, and reception (Aptel et al., 2009; Aptel and Pourjalali, 2001; Pan and Pokharel, 2007). Logistics processes in hospitals tend to be fragmented and performed across several departments (Landry and Philippe, 2004). Often the wrong people perform logistics activities in hospitals; e.g. nurses spend up to 30 per cent of their time on logistics activities (Bloss, 2011; Landry and Philippe, 2004).

HRM. Having the right people with the right training perform logistics activities is important in ensuring high performing logistics processes such as inventory management (Stanger et al., 2012). Education of employees is therefore considered best practice (Callender and Grasman, 2010). In addition, logistics organizations could benefit greatly from hiring employees with a clinical background (Landry and Philippe, 2004).

Centralization vs. decentralization. Literature shows a tendency towards centralization of activities. Centralization of distribution centers and storage facilities across several hospitals can lead to significant savings in staff and inventory costs and is considered best practice (Landry and Philippe, 2004). However, Yau and colleagues argue that some support services are better handled in patient care units and that remaining logistics activities should be consolidated in a central logistics department (Yau et al., 1998). The same argument is made for satellite pharmacies and decentralized pharmacists (Al-Shaqha and Zairi, 2000; Thomas et al., 2000).

Organizational setting. The logistics decision process is embedded in a highly complex social and organizational setting in hospitals. Hospitals consist of many different stakeholders with different perceptions, interests and goals (de Vries, 2011). Misalignment of incentives both within the hospitals and across the SC is one of the main challenges leading to poor SC performance (Callender and Grasman, 2010; McKone-Sweet et al., 2005). Medical interests tend to overrule financial and operational goals emphasized by hospital and logistics management (de Vries, 2011). To ensure high performing healthcare SCs, the support of executive management and their understanding of the strategic importance of SCM is therefore vital (Böhme et al., 2016; Callender and Grasman, 2010; McKone-Sweet et al., 2005).

The literature review shows that to improve healthcare logistics processes, managers must consider which departments perform the logistics activities, ensure the right human resources and skills, consider whether a centralized or decentralized organization is preferred, and finally acknowledge the complex organizational setting in which logistics processes and decisions are embedded. Table 3 provides and overview the sub-themes identified in literature. The importance of human resources and the organizational structure for the success of logistics and SCM efforts in healthcare is undeniable. The organizational aspect is the least explored theme in healthcare logistics, and more research is needed on how hospitals can improve logistics processes through organizational interventions.

Creating an integrative map of healthcare logistics literature

The four major themes identified in extant literature have been treated separately in the thematic analysis but can support each other toward the objective of improving healthcare logistics. Technologies can act as enablers of SCM and logistics management, e.g. (Böhme et al., 2016; Romero and Lefebvre, 2015; Xie et al., 2016), and appropriate IT solutions can enable the move towards a seamless SC, e.g. (Böhme et al., 2013; Chen et al., 2013; Mustaffa and Potter, 2009). Conversely, constantly evolving technologies pose a barrier for implementing SC practices in healthcare (Callender and Grasman, 2010) and the integration of IT systems between SC agents remains a continued challenge (Rautonen, 2007). Thus, technologies and logistics and SCM can affect each other both positively and negatively.

Technologies are not only enablers of SCM and logistics management but can also enable the automation of certain human tasks (Anand and Wamba, 2013; Bendavid et al., 2012; Kumar and Rahman, 2014). However, successful ICT implementation still requires the relevant set of skills and executive support (Anand and Wamba, 2013; Kumar et al., 2008; Xie et al., 2016). The human factor is also vital in the observed trend of centralized logistics activities in hospitals, which requires closer collaboration between clinical and logistical staff (Engelund et al., 2007). Thus, improved communication between centralized and decentralized personnel is vital to enhancing process performance (Thomas et al., 2000).

To fully realize the benefits of a technology, it must be aligned with other components of the system and with the overall strategy (Pinna et al., 2015). The implementation of technologies will consequently affect the design of processes (Anand and Wamba, 2013; Çakici et al., 2011; Kumar and Rahman, 2014). Conversely, to realize the benefits of technologies, the reengineering of processes is necessary (Chircu et al., 2014; Romero and Lefebvre, 2015). Implementing technologies and changes to processes may in addition require changes to the organization (Anand and Wamba, 2013; Romero and Lefebvre, 2015). Improving the healthcare SC requires hospitals to consider managerial and behavioral aspects (Spens and Bask, 2002). Lack of executive support and understanding is one of the main reasons for SCM and logistics initiatives failing in healthcare (Böhme et al., 2016; McKone-Sweet et al., 2005; de Vries, 2011). In addition, successful SCM requires careful management of the constituent SC processes (Spens and Bask, 2002)(Spens and Bask, 2002)(Spens and Bask, 2002). Thus, processes, technologies, SCM and the organization must be aligned to reach a common objective of improved performance.

Based on the thematic analysis and the discussion above, each paper has been categorized according to the themes they contribute to. Table 5 shows the number of papers contributing to each of the four main themes. Logistics and SCM received most attention in the reviewed literature (65%), followed by technology (59%), BPM (52%), and organization (35%). This distribution of literature indicates a need for more research on the organizational aspect of healthcare logistics and to some extent BPM. Most papers have a dominant theme but contribute to two themes (42%), mainly combined SCM/logistics-technology literature (17%). Some papers contribute to only one theme (30%), followed by three themes (16%) and lastly four themes (12%). The constellation BPM-SCM/logistics-technology are the three themes mostly researched in conjunction. The analysis shows that the field of healthcare logistics is inter-disciplinary and that more research is needed at the intersection of disciplines. For managers, this shows that the four areas are inter-related and can support each other or affect each other negatively.

Table 5. An integrative map of healthcare logistics literature; contributions of literature to each theme

	BPM	**SCM/logistics**	**Technology**	**Organization**	**# Papers**	**%**
4 themes	*X*	*X*	*X*	*X*	10	12%
3 themes	*X*	*X*	*X*		8	10%
	X	*X*		*X*	2	2%
		X	*X*	*X*	3	4%
2 themes	*X*	*X*			6	7%
	X		*X*		4	5%
	X			*X*	3	4%
		X	*X*		14	17%
		X		*X*	2	2%
			X	*X*	5	6%
1 theme	*X*				9	11%
		X			8	10%
			X		4	5%
				X	3	4%
# Papers	42	53	48	28	81	100%
%	52%	65%	59%	35%	100%	

Conclusions and agenda for future research

This literature review has enfolded existing literature within the field of healthcare logistics. From healthcare logistics literature, 81 papers were selected for a review to determine what is known and not known about how to improve healthcare logistics processes. To answer RQ1, four major themes were identified in literature in accordance with the different types of interventions identified for improving healthcare logistics processes. Each theme consists of a sub-theme specifying a particular type of intervention. An integrative map was created depicting how extant literature contributes to each of the four themes. Additionally, the contingent factors determining under which circumstances each intervention is recommendable as prescribed in literature have been identified for replenishment systems, i.e. a logistics and SCM sub-theme, and technological interventions. These contingent factors answer RQ2. For practitioners, this literature review allows decision makers in hospitals to make an informed decision to improve healthcare logistics processes. First, by identifying the specific interventions that exist and second, by ascertaining under which circumstances these interventions are recommendable. For researchers, this literature review identifies gaps in extant literature for future investigation. This literature is not without limitations and a significant amount of literature contributing with mathematical modelling is not included in this review but has been covered in previous reviews of healthcare management in general (Dobrzykowski et al., 2014) and materials logistics in particular (Volland et al., 2016). Furthermore, this review is limited to material flows and does not consider patient or staff flows. Based on the identified gaps in literature and the limitations of this study, an agenda for future research is proposed in the following.

Maturity of the research field. Case study research is the most applied methodology in healthcare logistics, which indicates an immature research field. This is supported by the fact that the reviewed papers are dispersed across 60 different journals and with 11% of the reviewed papers originating from the grey literature base. Thus, healthcare logistics is an emerging research field with room for more research to mature and develop the field further. Several quantitative studies have been conducted in healthcare logistics as reported by Dobrzykowski (Dobrzykowski et al., 2014), especially with the application of mathematical modelling. Other quantitative research approaches are needed, e.g. surveys or a mix of quantitative and qualitative methods.

Definitions. There seems to be some disagreement regarding what constitutes a JIT, stockless and VMI solution. A more clear definition of these three terms in healthcare logistics is necessary.

Under-researched themes. The most investigated themes are SCM/logistics and technology, whereas BPM and organizational aspects are under-researched. For BPM, an opportunity for future research lies in providing more detailed characteristics of specific logistics processes other than the flow of pharmaceutical products, blood products and sterile supplies. Performance measurement and benchmarking are the

BPM approaches that have received the most attention, but overall, literature on the application of BPM approaches remains scarce and provides an opportunity for further research. Investigating other BPM approaches than identified in this study would pose a novelty, e.g. TQM, lean and six sigma.

Logistics and SCM is the most investigated theme with 64% of the papers contributing to this theme. The reviewed JIT and stockless literature dates back to the 1990's and early 2000's, but the other sub-themes have experienced more recent attention, indicating emerging themes on the rise, particularly for SC integration and for logistics and SC innovation. Less investigated topics include single dose replenishment systems and responsive SCs. Additionally, other logistics and SC concepts such as agile, lean and leagile SCs could provide avenues for future research.

The most investigated type of technology is ICTs, closely followed by RFID and barcoding. Other existing technologies found in healthcare logistics and new technologies found in other fields provide opportunities for further research. Although RFID is one of the more investigated technologies, the applications and benefits of RFID have not been fully uncovered. Despite being the second most researched technology in this review, reviewed RFID literature only dates back to 2010, indicating a major interest from the healthcare field within a short amount of time.

The organizational aspect is the least researched type of intervention. This is in accordance with Privett and Gonzalves who identified HRM in the health SC as a main area for future research (Privett and Gonsalvez, 2014). In addition to the organizational sub-themes identified in the thematic analysis, suggestions for future research could be employee development, employee motivation, employee retention, and employee work conditions.

Inter-disciplinary research. The field of healthcare logistics is interdisciplinary and most of the reviewed literature contributes to more than one theme. Most inter-disciplinary research has been conducted at the SCM/logistics-technology intersection, but more research is needed at other intersections, particularly contributing to the SCM/logistics-organization and BPM-organization relations.

Contingent factors. Contingent factors were identified to aid decisions regarding replenishment systems and technological interventions, i.e. under which circumstances particular interventions should be implemented. Similar factors were not identified for the application of the sub-themes under SC design or the main themes of BPM and organizational change, which suggests a need for more research on this matter. Furthermore, there seems to be disagreement on some factors, e.g. when to apply VMI. Moreover, the factors were identified for particular interventions but may apply to other interventions than indicated in the reviewed literature. Other fields of research could provide valuable insights here.

Benefits. The benefits of each intervention have not been extensively mapped for a healthcare logistics setting, but have been indicated during the thematic analysis. Such a map would be helpful for decision makers to enhance the informed decision making process.

Learning from other industries. Compared to the manufacturing industry, logistics in healthcare is a relatively new field. Thus, research and practices in manufacturing could provide knowledge regarding other possible benefits that particular interventions could provide. Furthermore, other industries may be at the forefront of adopting new technologies that have not yet reached the healthcare industry. The prospective application of new technologies in healthcare logistics is therefore another potential research field.

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PAPER 2

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Factors Impacting the Design of Healthcare Logistics Processes

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Purpose: This paper aims to identify the factors impacting the decision to implement instances of technologies in healthcare logistics processes. Furthermore, this paper seeks to understand how managers can use knowledge about impact factors to design processes that fit the needs and preferences of the hospital.

Research design: A multiple case study is carried out at five Danish hospitals to investigate the bed logistics process. A technology assessment lens is applied to gain an understanding of the changes made in the process and the reasoning behind the process changes, particularly for implemented technologies.

Findings: A framework is developed consisting of seventeen decision criteria corresponding to the factors impacting the design of healthcare logistics processes. The decision criteria perceived as most important to the design of healthcare logistics processes relate to quality, employee work conditions and employee engagement.

Research limitations/implications: The findings of this study provide insights about the factors impacting the design of healthcare logistics processes. Differences in perceived importance of decision criteria enable 1) ranking of decision criteria, 2) prioritization of changes to be implemented, and 3) support in selecting a BPM approach and process strategy. The study is limited to five hospitals, but is expected to be representative of public hospitals in developed countries and applicable to similar processes.

Originality/value: The study contributes to the empirical research within the field of business process management in healthcare; particularly on how to design low cost, high quality logistics processes that reflect the needs and preferences of a hospital.

Keywords: healthcare logistics; process design; business process management; technology assessment

Introduction

Healthcare systems around the world face the challenge of rising healthcare costs. Expectations of high quality care together with an ageing population and more sophisticated treatments have led to more expensive healthcare provision (OECD, 2015; WHO, 2010). Thus, there is an increasing pressure to provide high quality care at lower costs. One opportunity for reducing healthcare costs is by addressing logistics expenditure in hospitals. Logistics activities account for more than 30% of hospital costs, half of which could be eliminated by applying best practices (Aptel et al., 2009; McKone-Sweet et al., 2005; Poulin, 2003). Main and supporting logistical flows in hospitals therefore hold great potential for cost reductions.

Hospitals are turning to manufacturing based supply chain management (SCM) best practices and business process management (BPM) concepts such as just-in-time (JIT) (Aptel and Pourjalali, 2001; Kumar, Ozdamar, et al., 2008; Kumar, DeGroot, et al., 2008), lean (Hicks et al., 2015; Joosten et al., 2009; Kollberg et al., 2007), total quality management (TQM) (Chen et al., 2004; Chow-Chua and Goh, 2000), business process reengineering (BPR) (Bertolini et al., 2011; Elkhuizen et al., 2006; van Lent et al., 2012) and automation (Granlund and Wiktorsson, 2013; Markin, 1994) in an effort to become more efficient and effective. However, hospitals are often left to their own experience to decide on a process design that suits their needs (van Lent et al., 2012). Thus, this paper investigates the factors impacting the design of healthcare logistics processes to support managers in deciding which process interventions to implement and which BPM approach or process strategy to apply.

Technology management decisions can significantly impact hospital costs and quality performance (Li and Benton, 2006). Introducing a technology in a process will invariably affect the process and its design (Attaran, 2003; Karimi et al., 2007). This study therefore investigates the factors impacting the design of logistics processes by examining why instances of technologies have been implemented in a bed logistics processes.

The potential for reducing costs through the application of SCM and BPM best practices motivate the research questions investigated in this paper. To narrow down the scope of the study, a technology assessment lens is applied as the implementation of technologies will impact the design of processes and furthermore improve process performance. The method used for assessing a technology depends on the type of technology (Douma et al., 2007). Thus, this paper aims to 1) identify the factors impacting the decision to implement instances of technologies in healthcare logistics processes and 2) to understand how managers can use this knowledge about impact factors to design processes that meet the needs and preferences of the hospital. Hence, the following research questions are investigated in this paper:

RQ1: Which factors impact the decision to implement instances of technologies in healthcare logistics processes?

RQ2: How do differences in perceived importance of such impact factors, both between hospitals and between impact factors, affect the design of healthcare logistics processes?

RQ3: How can factors impacting the decision to implement instances of technologies in healthcare logistics processes serve as decision criteria to improve healthcare logistics processes?

A multiple case study is conducted investigating instances of technologies implemented in the bed logistics process at five Danish hospitals. A set of factors influencing the design of healthcare logistics processes is then identified based on the multiple case study.

This paper is organized as follows. A literature review is provided linking BPM to technology assessment and justification in a healthcare logistics setting. The research method is then described, following an introduction to the case studies and a presentation of the results. Finally, the paper discusses and concludes on the results of the study.

Literature review

The following literature review covers four areas: 1) BPM in healthcare, 2) healthcare logistics, 3) technologies in healthcare logistics, and 4) technology assessment and justification. The literature review follows a sequence that logically links BPM to technology assessment and justification for a healthcare logistics setting. By providing this trail of evidence from literature, the key elements of the study aims, research questions and objectives are covered and the link between them established.

Business process management in healthcare

BPM can improve a company's performance and provide a competitive advantage (Ho et al., 1999; Hung, 2006; Liu et al., 2011). Zairi defines BPM as a structured approach to analyzing and continually improving fundamental activities in a company's operation (Zairi, 1997). The definition by Hung focuses more on how to achieve changes and describes BPM as an integration of BPR and TQM. He defines BPM as an integrated management philosophy and set of practices that includes both incremental change and radical change in business processes (Hung, 2006). Both views agree that continuous improvement is inherent to BPM.

Hospitals are complex systems consisting of unique and interrelated processes coordinated across several organizational units (Aronsson et al., 2011; Kannampallil et al., 2011; Lillrank et al., 2011). Problems are often specific to a healthcare context, making it difficult to standardize these processes (Helfert, 2009). Furthermore, healthcare processes are viewed as unpredictable, non-routine processes that make it hard to schedule production and to apply a process approach (Aronsson et al., 2011; Jarrett, 1998; Lillrank et al., 2011). However, whereas lean responds poorly to variability and seeks to smooth out demand variability, an agile process strategy responds well to variability (Naylor et al., 1999). Nevertheless, lean and healthcare are not irreconcilable concepts and several examples of lean applications in healthcare exist, e.g. as reported by Souza (Souza, 2009). To accommodate both the need for a rapid response to variability and the increasing pressure for efficiency, several authors suggest a leagile process strategy for healthcare delivery systems (Aronsson et al., 2011; Rahimnia and Moghadasian, 2010; Towill and Christopher, 2005).

Unpredictability in healthcare is a product of both artificial variation introduced by the system itself and natural variation inherent to a healthcare system (Litvak et al., 2005; Litvak and Long, 2000; Noon et al., 2003; Walley et al., 2006). Artificial variation can be reduced by eliminating poor hospital practices (Litvak et al., 2005; Walley et al., 2006), thus reducing waste and improving quality of care (Litvak and Long, 2000). Process redesign approaches such as lean and BPR aim to reduce waste in processes (Hammer, 1990; Hammer and Champy, 1993; Womack and Jones, 2003). Whereas lean focuses on continuous improvement with incremental changes, BPR has a more radical approach to change. Implementing quality management through both continuous improvement and BPR can lead to reduced operating costs and waiting time and an improved organizational structure in hospitals (Chow-Chua and Goh, 2000).

To ensure the success of BPM efforts, Trkman identified a set of critical success factors, which relate to three constructs: 1) process design, 2) organizational structure, and 3) technologies. First, business processes should be standardized and aligned with strategic objectives and a focus on continuous improvement should be ensured (Armistead et al., 1999; Davenport and Short, 1990; Hung, 2006; Trkman, 2010; Zairi, 1997). Second, organizational structure and business processes should be aligned. Thus, training, employee empowerment and employee engagement are vital at the employee level, and management commitment is essential at the managerial level to sustain changes (Armistead et al., 1999; Ho et al., 1999; Hung, 2006; Trkman, 2010). Finally, continued alignment of technologies is imperative to the success of BPM (Hung, 2006). Thus, together with human resources and organizational change, technologies are enablers of process redesign.

Managerial tools and concepts of SCM and logistics have not been systematically implemented in healthcare (Towill and Christopher, 2005; Yasin et al., 2002). Managers are often left to their own experience to decide which process management approach best fits their hospital (van Lent et al., 2012). Thus, although an agile approach is better at managing process variability, most literature focuses on lean rather than agility (Rahimnia and Moghadasian, 2010). More research is therefore needed on the application of BPM in healthcare, particularly when and how it should be applied. This paper proposes a framework that supports decision makers in designing logistics processes which accommodate the needs of a hospital.

Logistics in healthcare

Logistics relates to the movement and transmittal of goods, services and information (Lummus et al., 2001) and is closely related to SCM as, which is reflected in the definition of logistics management provided by the Council of Supply Chain Management Professionals (Council of Supply Chain Management Professionals, 2016):

> Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.

There has been a growing interest in the field of healthcare operations and SCM (Volland et al., 2016), including the selection and design of the service delivery system (Dobrzykowski et al., 2014). E.g. Spens and Bask expand a SCM framework by applying the framework to a blood transfusion supply chain (Spens and Bask, 2002) and Narayana and colleagues investigate the factors impacting the reverse pharmaceutical supply chain (Narayana et al., 2014).

A process oriented approach to SCM can improve supply chain performance (Aronsson et al., 2011; Kumar, Ozdamar, et al., 2008). Principles such as six sigma (Jin et al., 2008), Lean (Souza, 2009), JIT (Jarrett, 1998; Kumar, Ozdamar, et al., 2008; Pan and Pokharel, 2007), TQM (Heinbuch, 1995), BPR (Chow-Chua and Goh, 2000; Elkhuizen et al., 2006; Ho et al., 1999), and cellular operations (Parnaby and Towill, 2009) have therefore been applied to healthcare logistics processes. However, the extent of the field continues to be limited.

The process investigated in this paper is the bed logistics process, which includes the flow of beds and the flow of patients. A survey of Dutch hospitals revealed that the most prevalent process management approaches in patient logistics are care pathways and benchmarking, followed by BPR and Lean management. However, half of the survey hospitals had not achieved their goals (van Lent et al., 2012). This suggests a need for more research on how to successfully improve patient and bed logistics from a process perspective.

Beds are a scarce resource and hospitals are faced with both poor bed utilization and bed shortages (Bekker and Koeleman, 2011; Holm et al., 2013; Schmidt et al., 2013). At the same time, the growing demand for healthcare resources increases the pressure for better utilization of bed capacity (Bekker and Koeleman, 2011). A number of constraints in the bed logistics process contribute to the complexity of managing the process; e.g. single rooms, no mixed-sex rooms, incompatibility between pathologies, and contagiousness. Bed management units must solve these issues in a context of high uncertainty as treatment outcomes are not fully predictable and as emergency patients need immediate treatment (Schmidt et al., 2013). Consequently, changes are repeatedly made due to acute patients and inaccuracy in expected length of stay (Bachouch et al., 2012). Computer aided decision support can help overcome the challenges in the bed logistics process and improve bed utilization by taking different constraints into account (Schmidt et al., 2013). Operations research approaches such as simulation studies (Kim et al., 2000; Schmidt et al., 2013), scheduling (Bekker and Koeleman, 2011) and mathematical modelling (Bachouch et al., 2012; Utley et al., 2003) have been used to solve these optimization problems. Others have taken a more process oriented approach (Banerjee et al., 2008; Parnaby and Towill, 2009; Villa et al., 2009, 2014), but research in this area is more limited.

The provided literature study suggests a need for research on bed logistics, particularly on selecting the appropriate process design. This paper applies the less used process management approach to the bed logistics process and provides a framework that supports the assessment of process designs.

Technologies in healthcare logistics

Nurses spend as much as 30% of their time on logistics tasks such as tracking down medication and other supplies. Technologies can help care staff spend more time on patient care (Bloss, 2011; Granlund and Wiktorsson, 2013). Hence, technologies can improve process efficiency (Pokharel, 2005; Voss, 1988), provide cost savings, reduce data entry errors, and increase customer service levels (Pan and Pokharel, 2007). IT in particular can significantly influence an organization's overall logistics competence (Closs et al., 2006).

Information management. IT can dramatically improve the accuracy, reliability, speed and productivity of logistics processes in hospitals (Su et al., 2011). Wamba and colleagues provide an extensive literature review on the application of RFID in healthcare and identify three overall applications: 1) patient management, 2) asset management, and 3) staff management. Benefits include efficiency, quality and management gains (Wamba et al., 2013), increased productivity, and reduced inventory loss (Kumar and Rahman, 2014).

Barcodes and RFIDs can serve the same purpose. RFIDs have can provide more benefits, albeit at a higher cost. A study by Romero and Lefebvre found that combining the use of barcodes and RFIDs resulted in better inventory management and less inventory loss, decreasing the amount of manual labor, length of procurement cycles and number of recall activities (Romero and Lefebvre, 2015).

Materials transport. Automated guided vehicles (AGVs) are mobile robots that can autonomously navigate and transport items such as medicine, lab results, food, linen, equipment and other supplies, allowing nurses to spend more time with patients (Bloss, 2011; Granlund and Wiktorsson, 2013; Kumar and Rahman, 2014; Landry and Philippe, 2004). Another technology used for transporting items in hospitals is pneumatic tubes where items are transported in canisters by using compressed air. Pneumatic tube systems have been widely used in laboratory practices to transport items such as blood samples (Al-Riyami et al., 2014; Granlund and Wiktorsson, 2013; Jørgensen et al., 2013).

The described technologies perform different types of activities but can serve the same purpose, i.e. to free up time for care personnel. To decide on which technologies to implement, different assessment and justification methods can be applied.

Technology assessment and justification

There are several ways to assess and justify the implementation of a new technology. Technologies can be assessed by applying specific technology assessment methods. These technology assessment methods tend to focus on informing policy makers of the general impact of a new type of technology. E.g. health technology assessment informs policy makers about the efficacy, safety, and cost-effectiveness of technologies that solve a health problem and improve the quality of life (Ritrovato et al., 2015; WHO, 2015). However, this paper is not concerned with solving a health problem as such or with designing a new technology, but rather the justification of technologies.

Meredith and Suresh distinguish between three methods for technology justification: strategic, economic and analytic (Meredith and Suresh, 1986). The analytic approach includes techniques such as the weighted factor model and the Analytic Hierarchy Process (AHP), which is a special case of the general method Analytic Network Process (Saaty, 2004a, 2004b). However, the challenge with these analytic methods is that there is often not a framework available to which the method can be applied (Chan et al., 2001). This paper provides a framework to which analytic methods can be applied for assessing technological solutions as part of a logistics process design.

Hospitals implement different technologies due to different focus areas (Xie et al., 2016). Furthermore, organizations operate under different circumstances and the benefits reaped from a technology therefore differ (Chan et al., 2001). Hence, organizations must select a technology that best fits their specific needs. This study combines a process perspective with technology assessment by assessing the business process outcomes (Karimi et al., 2007).

Method

Research objectives, research design, data collection and data analysis are presented in the following.

Research objectives

The research objectives detail how the research questions are answered. To answer RQ1, challenges in healthcare logistics and reasons behind implementing changes in healthcare logistics were identified. The identified challenges and reasons for implementing technological instances were synthesized to encapsulate the factors impacting the decision to implement these technological instances. Thus, using the impact factors in a decision process will reflect factors already used in a decision process and additionally address challenges to improve process performance and reach organizational goals (Locke and Latham, 2002; VandeWalle et al., 2001). To answer RQ2, differences in perceived importance of the identified impact factors were established and compared to differences in process design, i.e. a cross-case analysis (Benbasat et al., 1987; Eisenhardt, 1989; Yin, 1994). To answer RQ3, a decision framework was developed based on the multiple case study to support managers in designing healthcare logistics processes of high quality at a lower cost.

Research design

There is a need for case study research in the field of operations management (McCutcheon and Meredith, 1993) and an increase in such studies has been observed in recent years (Barratt et al., 2011). A case study research design was chosen because it provides rich data and enables a deep understanding of a phenomenon (Yin, 1994). The investigated phenomenon is the improvement of healthcare logistics processes and the unit of analysis is the bed logistics process. The multiple case study consists of five hospitals located in the capital region of Denmark.

Data collection

Data was collected over a seven month period. The case study hospitals were chosen because they differ in size and specialization whilst being located within the same region. Hospital 1 served as a pilot for data gathering in the other hospitals (see hospital overview in Table 1). Both qualitative and quantitative data was collected. Data was collected mainly through interviews and observations and was carried out in three stages: 1) a preliminary stage, 2) a round of semi-structured interviews, and 3) a round of structured interviews to validate the results. In addition, different types of documents were gathered as background information from Hospital 1.

(1) The preliminary stage. The preliminary stage was carried out in Hospital 1, serving as a pilot study, with twelve open interviews and four process observation sessions. The twelve interviews were conducted with managers in the logistics department involved in the bed logistics process. Furthermore, clinical staff and employees with knowledge of data, technologies and improvement initiatives in the bed logistics process were interviewed. The observations were direct observations of each step of the bed logistics process with some interaction with the people involved. Furthermore, documents were collected that provided an overview of beds in the outpatient clinic, a standard operating procedure for handling beds, data on the number of dirty beds collected and cleaned, and admission and discharge data. The purpose of data collection in the preliminary stage was to learn about the bed logistics process, the challenges in the process, and any improvement potential. Although the nature of data

gathering in Hospital 1 resembled a pilot, data gathering was extensive enough to match the quality of data gathered in the other hospitals and was therefore included in the final study.

(2) Semi-structured interviews. A round of semi-structured interviews was then carried out with managers at each of the other four hospitals. These managers were responsible for the cleaning of beds. Furthermore, the bed logistics process at each of these four hospitals was observed, focusing on the part of the process for cleaning and for transporting beds. The data collected at this stage was then analyzed and a list of impact factors identified.

(3) Structured interview validation. A round of structured interviews followed with managers from each of the five case study hospitals. The impact factors identified in the first two data collection stages were presented in the structured interviews. Respondents were then asked to rank the identified impact factors on a scale from 0-10 according to importance for improving healthcare logistics processes. Interview guides were used for the interviews with questions related to the research questions and objectives. Additional guidelines were used to guide the observations. The interviews lasted between ½-1½ hours and the observations lasted 1-2 hours.

Analysis

The analysis follows the sequence of the research objectives. Challenges, implemented technologies, and reasons for implementation were identified through coding of interview and observational data (Corbin and Strauss, 2015; Miles et al., 2014). Data was coded to identify factors impacting the decision to implement changes in a process. Each identified factor was ranked according to importance for improving healthcare logistics processes. In the structured interviews, the impact factors were ranked by letting respondents assign values on a 0-10 scale; 0 being of no importance and 10 being of extreme importance to the improvement of processes.

As identified in the literature review, the success factors for BPM implementation can be divided into three dimensions: technology, organizational structure, and processes. These factors have similarly been identified as important for optimizing the supply chain (Mohanty and Deshmukh, 2000). Thus, technology, organizational structure, processes and logistics are inherently interrelated and the identified impact factors are grouped accordingly.

Data validity and reliability

To improve the validity of the results, a multiple case study was chosen as research design (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Yin, 1994). To increase reliability, a case study protocol was used to guide data collection (Yin, 1994). Interview guides, observation guides, and purpose of data collection were included in the protocol. Respondent validation was used to further improve the validity of the study (Yin, 1994).

Multiple data sources were used to enable triangulation of data, hence increasing reliability and providing stronger evidence to substantiate the identified constructs (Benbasat et al., 1987; Eisenhardt, 1989; Voss et al., 2002), i.e. impact factors. Examples of data triangulation were found where different data sources support the same argument. Conversely, some statements were found to contradict other sources of evidence; e.g. compared to what had been observed or what had been stated in another interview.

The chain of evidence linking data, analysis and results is found in the Results section and is displayed in table form (Table 2) as promoted by several authors (Eisenhardt and Graebner, 2007; Miles et al., 2014; Voss et al., 2002).

Case study research is situationally grounded whilst seeking a sense of generalizability. This ensures methodologically rigorous and practically relevant research (Ketokivi and Choi, 2014). This study is situationally grounded in bed logistics, but seeks generalizability for hospital logistics processes. The study targets practitioners in healthcare management, particularly managers in healthcare logistics.

Introducing the case study hospitals

The case study hospitals differ in size and specialization. Three of the five hospitals have a 24 hour emergency department whereas the other two hospitals provide an emergency clinic with limited opening hours. Table 1 provides an overview of the hospitals.

Table 1. Overview of case study hospital, beds and implemented technologies

Hospital	**# beds occupied**	**# actual beds**	**# beds cleaned/day**	**24h ED?**	**Implemented technologies**				
					Washing machine	*Equipment to (un)load mattress*	*Monorail*	*Barcodes*	*RFID*
Hospital 1	700	1,200	235	Yes			X	(X)	(X)
Hospital 2	600	800	250	Yes	X	X		X	
Hospital 3	500	1,200	175	Yes		(X)			
Hospital 4	300	560	110	No	X	X			(X)
Hospital 5	250	500	120	No	X	(X)		X	

The hospitals differ in the extent of technology adoption in the bed logistics process. The identified technologies include washing machines for bed washing, equipment to load and unload mattresses when washing beds, a monorail for bed transport, and barcodes and RFIDs for tagging beds. The parentheses in Table 1 indicate that the technology had been installed but was not used in everyday operations. This was due to either 1) the implementation had failed, 2) the technology had only been tested, or 3) further investments were needed to fully operate. The attempted implementation of a crane in hospital 3 failed because the crane could not endure water, and the crane in hospital 5 failed because employees refused to use it due to prolonged processing times. Hospital 1 had barcodes attached to all of the beds for repair purposes but lacked the software to enable bed management. RFID was tested at hospital 1 and 4, but had not been implemented due to political reasons.

The bed logistics process starts with the patient being admitted to the hospital and placed in a bed. During hospitalization, the patient is transported in a bed by transporters to and from treatments. Furthermore, the bed is cleaned in the ward by the cleaning department during their daily cleaning routine. When the patient is discharged, the dirty bed is transported to a central bed cleaning area by a transporter and cleaned by a central bed cleaning team. In some hospitals, beds are cleaned manually, in others they are cleaned automatically using special washing machines. One of the hospitals distinguishes between ‘slightly dirty’ and ‘dirty’ beds; slightly dirty beds are cleaned manually using disinfectant wipes and dirty beds are cleaned in a washing machine.

Results

Impact factors are identified based on case study data and ranked. A framework is developed based on the results and literature review.

Identifying impact factors in the bed logistics process

Seventeen impact factors were identified. Table 2 provides transparency on how the impact factors were derived from data.

A few of the impact factors are worth commenting on at this point. For *output quality*, all of the hospitals had encountered quality issues with the cleanliness of hospital beds, thus some hospitals had added process steps to ensure cleanliness. Hospital 4 claimed not to have quality issues anymore due to major quality improvement efforts.

Impact on related processes can be either of a positive or negative nature; e.g. a negative impact of increased workloads for other processes, or a positive impact of using washing machines for other items such as assistive aids. Table 3 summarizes the identified impact factors and how they relate to the constructs Logistics, Technology, Procedure and Structure.

Table 2. Derived decision criteria

Construct	Decision criterion	Description of decision criterion	Challenge	Technology: *Washing machine*	Technology: *Equipment to (un)load mattresses*	Technology: *Monorail*	Technology: *Barcodes*	Technology: *RFID*	Reason for implementing technology
Logistics	*Lead time*	Time elapsed from a significant point in time until a significant end time.	Washing machines take longer than a manual wash. Some (un)loading equipment for mattresses failed due to employees not willing to wait for equipment to finish.	X					One of the washing machines was chosen because it can wash several beds at a time.
	Value-added time	Time spent on process steps that do not add value to the patient or departments.	Excessive transporting time to other building. Waiting time due to bottlenecks. Over processing/cleaning some beds.	N/A					N/A
	Security of supply	Ensuring that the right bed and mattress is available at the right time.	Difficulties ensuring enough clean beds. Difficulties ensuring the right bed (and mattress) for the right patient. It is not known whether or not the available resources will match the need of resources.	N/A					N/A
	Traceability	Enabling traceability and localization of items in the process.	The whereabouts of the beds is unknown. Data on the history of the bed is not available.				X	X	Enables traceability of beds, data capturing, traceability, and planning.
Technology	*Degree of automation*	Enabling coordination and planning of activities through data availability.	Lack of data availability. Insufficient data on bed and mattress needs. A lot of the data is manually registered. Difficulties planning resources due to lacking data.			X			Use staff when human att. required.
								X	Using RFID to capture data is more automated than for barcodes.
	Information management	N/A	N/A				X	X	Capture data on beds, enable planning, study/improve the bed flow.
	Environmental consid-erations	Considering the use of water, chemicals, electricity etc.	Excessive use of water either through manual wash or automated wash.	X					To reduce the use and waste of water for washing bed.
	Consistency	The extent to which the process is performed the same.	Lack of standard operating procedures.	X					To ensure consistent output quality, i.e. the cleanliness of all cleaned beds.
	Future proofing	Ensuring that a solution is viable in the long run in relation to the overall	The placement of the bed cleaning area increases transporting time for beds. The monorail	N/A					N/A

		strategy, the future need for capacity, and the future technology investments.	transports beds to the bed cleaning area. The tact of the monorail leads to inefficiencies in the process. System is not easily replaced.						
Procedure	*Risk of mistakes*	The risk of making mistakes in the process. Risk mitigating mechanisms in place.	Lack of process knowledge. Lack of systems knowledge. Lack of incentive to perform process correctly.	X					To avoid mistakes in the process. A simple solution ensures ease of use for the employees and makes it easier to match the right competencies
	Consistency	The extent to which the process is performed the same.	Lack of standard operating procedures.	X					To ensure consistent output quality, i.e. the cleanliness of all cleaned bed
	Future proofing	Ensuring that a solution is viable in the long run in relation to the overall strategy, the future need for capacity, and the future technology investments.	The placement of the bed cleaning area increases transporting time for beds. The monorail transports beds to the bed cleaning area. The tact of the monorail leads to inefficiencies. The system is not easily replaced.	N/A					N/A
	Impact on re-lated processes	Other processes could be affected negatively due to increased work load.	Increased work for related processes as a consequence of changes to the bed cleaning process.	X					To possibly use the washing machines for other tasks.
	Output quality	Quality of output, i.e. the cleanliness of beds. Differs from risk of mistakes as output quality would also depend on tools/machinery.	Difficulties living up to cleaning requirements. Lack of quality standards. Lack of quality measures. Insufficient quality controls.	X					To ensure consistent output quality, i.e. the cleanliness of all cleaned bed
Stucture	*Competence shifts*	Handovers that happen between resources in the process.	Handover should be done by a different personnel group to avoid mistakes and rework	X					A simple solution ensures ease of use for the employees and makes it easier to match the right competencies.
	Competence match	The extent to which employees have the necessary competencies to perform a task.	Lack of systems knowledge. Wrongful handovers between departments – beds are not handed over correctly.	N/A					N/A
	Unnecessary process	N/A	N/A	X		X			To reduce the use of employee resources.
	Employee engagement	The extent to which the employees feel motivated to perform a task and incentives for performing tasks.	Low productivity. Lack of incentives and motivation to perform tasks and to use technologies. Lack of feeling of responsibility and pride.	N/A					N/A
	Employee work conditions	The conditions under which employees work. E.g. access to sunlight, ergonomics etc.	Poor work condition. Physically strenuous tasks.		X	X			To alleviate employees from strenuous work.

Table 3. List as impact factors serving as decision criteria

Logistics	Technology	Procedure	Structure
• Lead time • Value-added time • Security of supply • Traceability	• Degree of automation • Information management • Environmental considerations	• Risk of mistakes • Consistency • Future proofing • Impact on related processes • Output quality	• Competence shifts • Competence match • Unnecessary process • Employee engagement • Employee work conditions

Ranking the identified impact factors

Table 4 provides an overview of how the hospitals have weighted each of the identified impact factors. The table is sorted in descending order according to the average weight and includes the standard deviation for each impact factor. The association of impact factors to the constructs logistics (L), technology (T), procedure (P) and structure (S) is indicated in the table.

Table 4. Decision criteria with assigned weights of importance

Decision criteria	**Low techn. adoption**	**Medium technology adoption**			**High techn. adoption**	**All hospitals**	
	Hospital 3	Hospital 1	Hospital 4	Hospital 5	Hospital 2	Ave-rage	SD
Risk of mistakes (P)	10	10	10	10	10	10.0	-
Employee work conditions (S)	10	8	10	10	10	9.6	0.9
Consistency (P)	10	7	10	10	10	9.4	1.3
Employee engagement (S)	10	7	10	10	10	9.4	1.3
Security of supply (L)	10	7	10	10	10	9.4	1.3
Environmental considerations (T)	10	7	10	8	10	9.0	1.4
Value-added time (L)	9	5	10	8	10	8.5	2.1
Lead time (L)	10	4	10	8	10	8.4	2.6
Information management (T)	10	5	10	9	8	8.4	1.8
Impact on related processes (P)	10	5	8	9	10	8.3	2.0
Future proofing (P)	9	4	8	10	10	8.0	2.4
Output quality (P)	10	9	(-)	10	10	7.8	4.4
Degree of automation (T)	9	6	7	7	10	7.8	1.6
Traceability (L)	8	7	10	10	2	7.4	2.9
Unnecessary process (S)	9	3	8	(-)	5	6.3	2.8
Competence shift (S)	10	2	8	7	1	5.6	3.9
Competence match (S)	4	3	10	10	1	5.6	4.2

A few comments on the validity of the results in Table 4 are necessary. First, Hospital 1 weighted the decision parameters more nuanced and lower than the other hospitals. This could reflect either a different interpretation of the scale or simply a lower perceived importance of the decision criteria. Furthermore, all hospitals seem to agree that *output quality* is of high importance. Hospital 4 had diligently addressed their quality issues through different initiatives, thus did not assign a high weight to *output quality*. However, the fact that the hospital had invested substantial efforts to reach the current level of quality indicates that output quality is indeed important and that the weighting does not reflect the manager's actual view.

The case study hospitals have different levels of technology adoption in the bed logistics process (see Table 1). To ensure that the weighted importance of impact factors is not merely a product of technology adoption levels in the organization, the hospitals were grouped in Table 4 according to their level of technology adoption in the bed logistics process. Hospital 3 uses no technologies in daily operations whereas Hospital 2 has adopted three types of technologies. The use of technology in the bed logistics process at Hospital 1, 4 and 5 is somewhere in the middle. Table 4 shows that the *degree of automation* is the only impact factor that shows a consistent pattern in relation to technology adoption. For the hospitals with either high or low technology adoption, the degree of automation is considered of high importance. For the hospitals with medium technology adoption, the importance was considered slightly lower.

In summary, most hospitals agreed that the impact factors identified in the interviews are important for improving healthcare logistics processes as none of them have received low average scores. Furthermore, apart from *degree of automation*, the importance of the impact factors did not seem to depend on the level of technology adoption.

High ranking impact factors

The highest ranking impact factors are also the factors that exhibit the most agreement amongst respondents, i.e. low standard deviation (SD). The highest ranking impact factors are discussed in the following. The *quality* related impact factors are discussed in conjunction, whilst *employee work conditions* and *employee engagement* are discussed separately.

Quality related factors. The highest ranking impact factors relate to *quality*, i.e. *risk of mistakes* and *consistency*. *Output quality* is included here, as the ranking does not reflect actual perceived importance, particularly regarding Hospital 4 (as explained in the previous section). This hospital introduced additional steps to ensure the cleanliness of beds upon patient discharge. Furthermore, all beds would undergo thorough cleaning and maintenance once a month. Some hospitals had implemented washing machines to improve the quality of the output, i.e. a clean bed. All these measures relate to *output* *quality*. Moreover, these processes lead to higher *consistency* in the cleanliness of beds. In addition to the central bed cleaning, beds are also cleaned in the wards during patient hospitalization as part of the daily cleaning routine. Cleaning is performed by cleaning staff and quality controls are performed by supervisors on a sample of cleaning jobs. Employees undergo extensive training, and standard operating procedures are in place to ensure quality. However, handovers between employee groups increases the *risk of mistakes*. Poor collaboration between departments and lack of performance measures, and consequently employee accountability, has resulted in continued errors in handovers.

Employee work conditions. The work conditions for employees have improved greatly over the years. The centralized bed cleaning provides better ergonomic work conditions than decentralized bed cleaning in wards, which still happens in other hospitals. One of the ergonomically challenging tasks is the loading and unloading of mattresses when beds are cleaned. Some hospitals have therefore implemented equipment for this task. One hospital implemented a monorail to ease transport to a separate bed cleaning facility. The monorail continues through the bed cleaning area providing a better ergonomic position for the manual bed cleaning process.

Employee engagement. One of the main challenges in the bed logistics process is employee absenteeism. Cleaning tasks and patient transport are considered dull, repetitive tasks that are physically demanding. Some hospitals have restructured the organization so that transporters are jointly responsible for the entire hospital rather than their own clinical department. According to one of the transporters, this has led to a lower sense of responsibility:

> We used to be responsible for each our department, but today we have a joint responsibility for the whole hospital. There’s no longer a sense of responsibility. For example, you wouldn’t take a dirty bed with you on your way back even if you pass one in another department.

However, a sense of pride in the work of bed cleaning employees was observed at one of the hospitals where management had made an effort to install a sense of pride and understanding of the significance of their work. E.g. the beds are made with the same crisp corners as in a hotel.

Another challenge for the hospitals is low staff retention rates. The hospitals pay for extensive training of employees, acquiring skills that are sought after in the better paid private sector. The lack of continuity in the staff base poses challenges for the quality of cleaning. Particularly in the wards, a significant difference in the quality of work has been observed for experienced staff compared to new or temporary staff.

In summary, hospitals have introduced several measures to address the challenges related to *quality*, *employee work conditions* and *employee engagement*. Hospitals have come a long way in improving *quality* and *employee work conditions,* although some challenges remain. *Employee engagement* continues to be a significant challenge.

Impact factors with low consensus

The impact factors with low consensus, i.e. high standard deviations, are incidentally also the lowest ranking impact factors (see Table 4). The following presents how these impact factors are reflected in the bed logistics process design.

Competence match. Hospital 1, 2 and 3 do not see *competence match* as an important impact factor. Interestingly, Hospital 2 is the same hospital that stressed the importance of a simple washing machine solution that is easy for the employees to use. Furthermore, the Hospital 1 case study provides supporting evidence that *competence match* is imperative in ensuring correct handovers. An elaboration on this matter follows.

Competence shifts signify the number of handovers between resources in a process. Hospital 1 and 2 consider *competence shifts* of low importance. However, Hospital 1 has experienced several challenges when it comes to handovers as items are erroneously left in beds, disrupting the automated transport activity and causing downtime and a need for maintenance. It would seem that the manager is either not aware of this challenge or simply does not view it as an important issue. The issue could be resolved through training of logistics and clinical personnel; thus, competence shifts are closely related to *competence match*. Finally, *competence shifts* are closely related to *traceability* as technologies can be used to register handovers in the process.

Traceability. Hospital 2 is the only hospital that does not view traceability as an important decision criterion. However, Hospital 2 is one of the hospitals that have actually invested in barcode technology for traceability in the process. Thus, there seems to be some inconsistency between the use of barcodes to ensure traceability and the statement that traceability is not important. The use of track and trace technologies is limited for most of the case study hospitals, but most hospitals perceive traceability as important.

Unnecessary process. All hospitals stated that the financial aspect of investing in a potential technology should be considered. Thus, no hospital would venture into an investment without performing some sort of cost-benefit analysis. There seems to be a discrepancy between the perceived low importance of an *unnecessary process* and a strong emphasis on the financial aspect. This indicates that some of the managers may not want to admit to cutting resources. Conversely, as one of the bed cleaning managers pointed out:

> Automation is important for improving efficiency. However, we must also think of the people working in these jobs – it will be difficult for them to find other jobs. I believe in future solutions that include both automation and people.

Thus, there seems to be a sense of responsibility from management to ensure jobs for these employees. Another manager raised this point and referred to their social responsibility.

In summary, for the impact factors with low consensus, the perceived low importance of an impact factor often did not match with other statements or past behavior. This suggests that these particular decision criteria should have been assigned higher values to reflect their actual perception importance, e.g. for *competence shifts* and *competence match*.

Framework development and implications for decision making

Based on the literature review and the results of this study, a framework is proposed to support managers in deciding how to improve healthcare logistics processes. The proposed framework is depicted in Figure 1 and consists of three stages: 1) identifying the subject of analysis, 2) analyzing the subject, and 3) providing a decision on instances of technologies and other process interventions to implement. In the present study, the subject is the bed logistics process, which can be analyzed by prioritizing the identified decision criteria and applying a strategic (descriptive) or analytic (quantitative) approach. Such an analysis would highlight areas for improvement, prompting suggestions for process interventions. Furthermore, the framework can support the decision regarding a BPM approach or process strategy, e.g. lean, JIT, TQM, BPR. E.g. a particular focus on quality would promote quality management approaches such as TQM, whilst a particular focus on lead time might promote a JIT approach.

Differences in perceived importance of impact factors will reflect the strategy and thus the needs and preferences of the hospital. The findings of this study suggest that the perceived importance of impact factors has implications for decision making. First, the study shows that the perceived importance of impact factors may differ but that certain impact factors are perceived of high importance across all hospitals. These aspects should therefore be considered when assessing possible changes to a process. Second, the differences in perceived importance of impact factors affect the process design, i.e. enables prioritization of potential changes to process steps and implementation of technologies. E.g. quality is perceived of high importance and both process steps and technologies had been implemented to address any quality issues. Third, the framework provides support in selecting a BPM approach and process strategy.

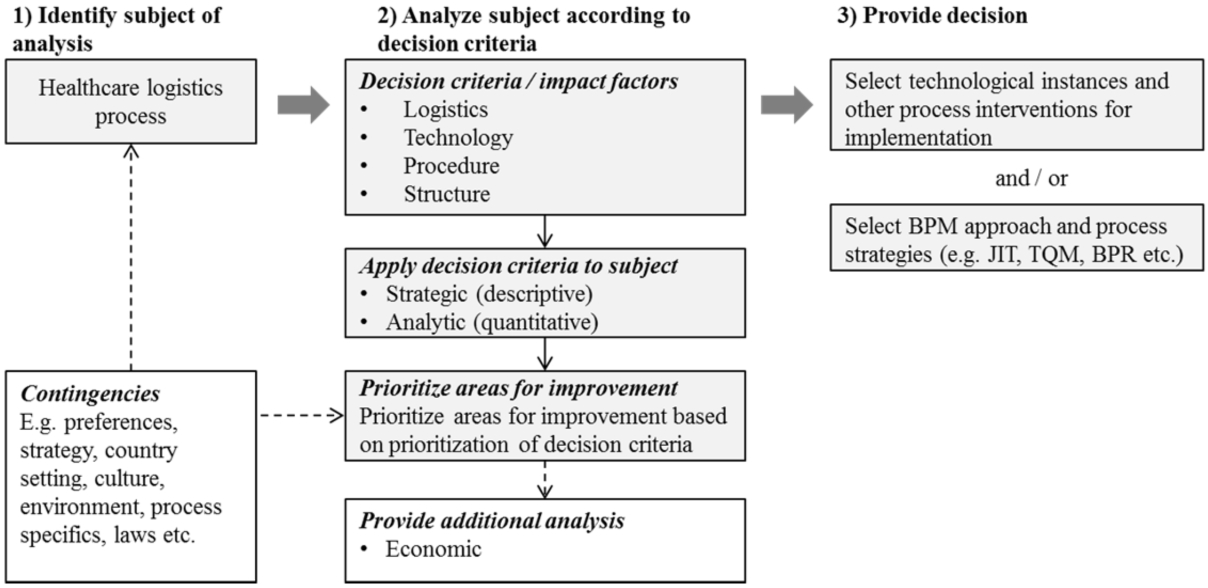

Figure 1. Developed decision framework for improving healthcare logistics processes

Discussion

To answer RQ1, a set of 17 impact factors was identified. Apart from the *degree of automation*, the study shows that the impact factors as decision criteria do not depend on the existing level of technology adoption. The identified impact factors each relate to one of the constructs logistics, technology, procedure and structure. Thus, each of these four aspects of a healthcare delivery system should be considered and balanced when making changes to a logistics process, much like balancing the four perspectives of the Balanced Scorecard (Kaplan and Norton, 1992). Thus, the impact factors can be used at a more strategic level as well as an operational level for designing processes. Hence, SCM and logistics should be viewed as a competitive advantage rather than a cost center (Fernie and Rees, 1995; Lambert et al., 1998).

To answer RQ2, the impact factors were ranked to identify the high ranking/high consensus impact factors and low ranking/low consensus impact factors. The impact factors perceived as most important for designing a healthcare logistics process relate to *quality*, *employee work conditions* and *employee engagement*. Improvement of these aspects should therefore be incorporated in the process design. These three concepts have been treated in existing BPM and logistics literature. Thus, the *quality* concept is an important part of BPM, which is rooted in total quality management from the 1980's (Hung, 2006; Zairi and Sinclair, 1995). On the point of *employee work conditions*, poor ergonomics in logistics and manufacturing has shown to lead to worker injuries such as musculoskeletal disorders and has lately received more attention in literature, e.g. (Andriolo et al., 2016; Grosse et al., 2015; Keller and Ozment, 2009). Both poor *employee work conditions* and low *employee engagement* can lead to injuries, high absenteeism and high turnover rates, which in turn can be costly to the employer.

Studies have shown that incorporating human factors in an operating model, e.g. by involving workers in the design of a process, can improve the outcome for both employees and production (Grosse et al., 2015; Guimarães et al., 2015). Furthermore, employee involvement is vital to the success of BPM efforts (Hung, 2006). Thus, the findings of this study align with other streams of literature.

The case study hospitals had improved over the years in terms of *quality*, *employee work conditions*, and *employee engagement*, which was evident in the processes. Although the processes differed, all hospitals had taken measures to improve *quality* through the implementation of technologies and/or additional process steps. *Employee engagement* continues to be a challenge due to the nature of the job and lack of financial incentives. However, the sense of pride and worth installed in the employees at one of the hospitals could be a learning point for others.

The impact factors with least consensus regarding the importance to the redesign of healthcare logistics processes are *competence shifts*, *competence match*, *traceability* and *unnecessary processes*. *Competence shifts* and *competence match* in particular are viewed differently and do not seem to receive the attention they deserve. Similarly, a study by Keller and Ozment shows that logistics managers often do not focus on building employee knowledge and driving employee success (Keller and Ozment, 2009). However, training of both clinical and support staff to achieve the right *competence match* can reduce errors and ensure correct handoffs, i.e. improve quality. Training is therefore an important enabler of the successful redesign of process (Ho et al., 1999; Hung, 2006; Trkman, 2010). Still, too many *competence shifts* or handoffs lead to inefficiencies and inevitable errors and misunderstandings in a process (Hammer and Champy, 1993; Parnaby and Towill, 2009). *Traceability* can support *competence shifts* and *competence match* by ensuring visibility in a process and accountability for each process step and handover. Closely related to *traceability* is the *degree of automation,* which can support *traceability*. Finally, *unnecessary processes* in an organization correspond to waste in a BPM context and should be eliminated (Hammer, 1990; Hammer and Champy, 1993; Womack and Jones, 2003). Except for *competence shifts* and *competence match*, the case study hospitals seem to consider the low consensus impact factors more than they let on. Moreover, hospitals could benefit from paying more attention to *competence shifts* and *competence match* both within and outside of the logistics organization. The lack of respect and recognition of the importance of logistics activities found in the case study is an example of how logistics and the benefit of logistics need to be marketed to the rest of the organization to fully reap the potential of logistics services (Ralston et al., 2013).

In general, all hospitals had centralized the organization and activities related to bed cleaning and bed transport. This increased the *competence shifts*, which in turn increased the *risk of mistakes*, negatively affecting the *quality* in the process. Conversely, it allowed for more specialized personnel and more efficient processes.

This is in line with another current trend in Danish hospitals to centralize tasks, e.g. for food services (Engelund et al., 2007).

A framework is suggested to address RQ3. The framework intends to support managers in making decisions about how to improve healthcare logistics processes. Applying the framework enables managers to assess different interventions, BPM approaches and process strategies for a healthcare logistics process. The framework draws on the types of technology justification methods proposed by Meredith and Suresh (Meredith and Suresh, 1986). When redesigning a healthcare logistics process, the impact factors can be used as decision criteria to qualitatively describe and compare possible solutions. Thus, different process strategies and technologies can be evaluated based on the proposed impact factors to identify a solution that best fits the needs of the hospitals. For a quantitative approach, analytic methods such as AHP or ANP can be applied by using the impact factors as variables to quantitatively rank solutions (Saaty, 2004a, 2004b). Thus, the impact factors can be used as decision criteria in a framework for analytic decision models. AHP has been used for similar purposes such as determining process performance for different process designs (Frei and Harker, 1999), health technology assessment (Ritrovato et al., 2015), technology justification (Meredith and Suresh, 1986), and benchmarking logistics performance (Korpela and Tuominen, 1996). The decision criteria could also provide areas for benchmarking process performance and ultimately identifying best practices. Thus, the prioritization of the decision criteria brings attention to areas that should be improved first.

Conclusion

This paper adds to the limited empirical research on BPM within the field of healthcare logistics. The study focuses on assessing and selecting a process design for a bed logistics process. A multiple case study of five Danish hospitals was carried out, based on which a set of 17 impact factors was identified for improving healthcare logistics processes. Each of these impact factors relates to one of the constructs logistics, technology, procedure or structure. These impact factors are thus aligned with the critical success factors of PBM and the importance of the logistics environment. The study suggests that these impact factors should be considered when improving healthcare logistics processes. However, some impact factors are considered more important than others.

The most important impact factors were identified by letting interviewees rank the factors according to importance for improving healthcare logistics processes. The most important impact factors relate to *quality*, *employee work conditions*, and *employee engagement*, which all affect cost and quality of logistics services. The results of this study show that the perceived importance of these impact factors will affect the design of a process. Hence, the case study hospitals had implemented measures to improve quality and employee work conditions. *Employee engagement* continues to be a challenge. However, installing pride and a sense of worth in the jobs of employees had proven effective in one of the hospitals. Thus, the results of the study stress the importance of incorporating human factors in the design of healthcare logistics processes and found that human factors have implications for correct handovers and quality in the process. Furthermore, the results suggest that decision makers should focus more attention on *competence match* and *competence shifts*, i.e. handovers, as these factors have implications for the efficiency and effectiveness of the processes.

A framework was developed based on the multiple case study. The framework supports decision makers in assessing and selecting a process design that best fits the preferences and needs of the hospital. The preferences and needs are considered in relation to the impact factors, which serve as decision criteria in the framework to determine the preferred process strategy; e.g. whether a lean or agile process strategy is preferred. Furthermore, the framework provides a basis for applying analytic methods such as ANP and AHP to rank possible process designs, e.g. to decide whether RFID or barcodes should be implemented or whether additional quality assuring process steps should be incorporated in the process design. A better basis for decision-making is provided by proposing a structured approach to the decision-making process. This framework is one step in the direction of managers no longer merely depending on their own experience to decide on a process design or BPM approach.

This study is subject to some limitations. First, the findings are limited to a Danish setting. Second, the findings are specific to a healthcare context. Third, the financial implications are not included in this study but are considered complementary to the framework. The findings of this study are expected to be true for hospitals that operate under similar conditions, i.e. large public hospitals located in developed countries. However, further studies are needed to validate this. Other areas for future research include the organizational aspect; human factors in particular are sparsely researched for healthcare logistics.

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PAPER 3

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MEASURING PROCESS PERFORMANCE WITHIN HEALTHCARE LOGISTICS - A DECISION TOOL FOR SELECTING TRACK AND TRACE TECHNOLOGIES

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ABSTRACT

Monitoring tasks and ascertaining quality of work is difficult in a logistical healthcare process due to cleaning personnel being dispersed throughout the hospital. Performance measurement can support the organization in improving the efficiency and effectiveness of processes and in ensuring quality of work. Data validity is essential for enabling performance measurement, and selecting the right technologies is important to achieve this. A case study of the hospital cleaning process was conducted at a public Danish hospital to develop a framework for assessing technologies in healthcare logistics. A set of decision indicators was identified in the case study to assess technologies based on expected process performance. Two aspects of performance measurement were investigated for the hospital cleaning process: what to measure and how to measure it.

INTRODUCTION

Logistical processes are essential for a hospital to function and in providing services for patients. Improving the efficiency and effectiveness of healthcare processes not only economizes on resources but also provides supports in reaching organizational goals (Gleason & Barnum, 1982; Mentzer & Konrad, 1991). Measuring the efficiency and effectiveness of a process can motivate employees and induce learning in order to improve processes (Neely, Gregory, & Platts, 2005). In a healthcare logistics context, employees will often perform tasks in various parts of a hospital without close management control. The lack of control and the dispersion of employees make it difficult to assess individual and process performance. Thus, from a principal-agent point of view, there is a need to measure and monitor the process (Kathleen M. Eisenhardt, 1989; Melnyk, Stewart, & Swink, 2004). Technologies such as RFID, barcodes and portable job agents can capture data in a process and enable process measurement (Ferrer, Dew, & Apte, 2010; Sarac, Absi, & Dauzère-Pérès, 2010). When measuring several performance indicators, one technology may not fit all, and a range of different technologies may be needed to enable performance measurement. Selecting the appropriate technologies for capturing data is important to ensure data validity and enable performance measurement.

A hospital is a complex system where a network of organizational units interact to perform various processes (Kannampallil, Schauer, Cohen, & Patel, 2011; Plsek & Wilson, 2001). The level of complexity can be determined by the interrelatedness between parts of a system and the uniqueness of those relations (Kannampallil et al., 2011; Simon & Cilliers, 2005). The uniqueness of healthcare processes stems from the unpredictable hospital environment as the course of treatment differs for each patient (Jarrett, 1998). The uniqueness of the hospital processes means that certain conditions are intrinsic to a hospital context. Furthermore, the important role of the patient in the outcome of health services differs from other industries with a more production oriented focus (Lillrank, Groop, & Venesmaa, 2011). Thus, the decision criteria that are valid in other industries may not apply in a hospital setting.

The decision criteria for assessing technologies to measure process performance within healthcare logistics are investigated in this paper. This study aims to develop a framework that serves as a decision support tool for logistics management within healthcare. The purpose of the tool is to assess technologies that enable performance measurement. The framework is developed by answering the following research question (RQ): How can decision indicators identified in a hospital cleaning case be used to assess technologies for measuring process performance in a logistical healthcare process?

A REVIEW OF THE LITERATURE

Literature within the field of healthcare logistics is reviewed to understand what healthcare logistics involves. The technologies used in healthcare logistics are then found in literature and the need for assessment methods is identified.

Understanding Healthcare Logistics

In one of the early definitions of logistics, the change in form and location of inventory was viewed as the main value-added process in materials logistics management (Bowersox, Carter, & Monczka, 1985). The term logistics has evolved over time from a narrow definition focusing on the reduction of inventories to a more broad definition (Cooper, Lambert, & Pagh, 1997). Several and more elaborate definitions of logistics have since been proposed. One of the widely used definitions of logistics is that of the Council of Supply Chain Management Professionals who defines logistics as 'that part of the supply chain process that plans, implements, and controls the efficient flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements' (Council of Supply Chain Management Professionals, 2015). Lummus and colleagues provide a similar definition of logistics as 'planning, implementing and controlling efficient, effective flow and storage of goods and services from the beginning point of external origin to the company and from the company to the point of consumption for the purpose of conforming to customer requirements. Logistics is generally viewed as within one company, although it manages flows between the company and its suppliers and customers' (Lummus, Krumwiede, & Vokurka, 2001). Controlling the flow of goods from point of origin to point of consumption in order to meet customer requirements seems to be recurring elements for the latter definitions. For this paper, logistics will be defined as by the Council of Supply Chain Management Professionals, and healthcare logistics is then logistics within a healthcare context.

The cost of providing healthcare has been rising and the pressure to provide healthcare services at lower costs has increased (OECD, 2013). The logistical costs in a hospital account for more than 30% of hospital expenditure (Poulin, 2003). Reducing costs related to healthcare logistics therefore provides an opportunity for addressing the challenge of increasing healthcare costs. Studies have investigated how the logistical activities in a hospital are performed and the opportunities for improving processes to reduce costs by implementing improvement initiatives such as just-in-time systems (Aptel & Pourjalali, 2001; Jarrett, 1998, 2006; A. Kumar, Ozdamar, & Ning Zhang, 2008; S. Kumar, DeGroot, & Choe, 2008), innovation processes (Lee, Lee, &

Schniederjans, 2011; Su, Gammelgaard, & Yang, 2011), Lean (Hicks, McGovern, Prior, & Smith, 2015; Joosten, Bongers, & Janssen, 2009; Kollberg, Dahlgaard, & Brehmer, 2007; Poksinska, 2010; Souza, 2009), TQM (Chen, Chen, Wu, & Lin, 2004; Chow-Chua & Goh, 2000; Pinna, Carrus, & Marras, 2015), Six Sigma (Jin, Switzer, & Agirbas, 2008; Lifvergren, Gremyr, Hellström, Chakhunashvili, & Bergman, 2010) , and Business Process Reengineering (A. Kumar et al., 2008; A. Kumar & Rahman, 2014). These improvement initiatives are all process oriented. Healthcare logistics processes have been investigated to some extent in literature, including medical supply (A. Kumar et al., 2008), pharmaceutical supply (Mustaffa & Potter, 2009; Romero & Lefebvre, 2015), patient flow logistics (Kriegel, Jehle, Dieck, & Tuttle-weidinger, 2015; Lillrank et al., 2011; van Lent, Sanders, & van Harten, 2012; Villa, Barbieri, & Lega, 2008; Villa, Prenestini, & Giusepi, 2014), sample transports (Al-Riyami et al., 2014; Jørgensen, Jacobsen, & Poulsen, 2013), and bed logistics (Feibert & Jacobsen, 2015; Schmidt, Geisler, & Spreckelsen, 2013; Utley et al., 2003). However, other logistical processes exist in a hospital such as laundry management, waste management, catering, mail service, security, cleaning, and managing surgical tools (Aptel & Pourjalali, 2001; Granlund & Wiktorsson, 2013; Jørgensen, 2013; A. Kumar & Rahman, 2014; Pan & Pokharel, 2007). Many of these hospital logistics services will often be outsourced, especially cleaning, security and catering (Moschuris & Kondylis, 2006). The literature survey shows that several logistical healthcare processes have not been explored in literature. Patient flow logistics has been studied more extensively, whereas the study of other logistical healthcare processes is limited.

The process improvement methods mentioned above can reduce waste in healthcare processes. However, healthcare processes face variability in demand and should not only look to lean process strategies but also agile process strategies (Rahimnia & Moghadasian, 2010). Aronsson and colleagues therefore contend the need for a supply chain management perspective that utilizes lean to reduce waste, and uses agility to cope with uncertainty (Aronsson, Abrahamsson, & Spens, 2011). To provide a supply chain management perspective, a number of studies have focused on logistical processes for the entire supply chain (Aronsson et al., 2011; de Vries & Huijsman, 2011; A. Kumar et al., 2008; Lillrank et al., 2011).

The cost of supplying a hospital can be divided into the cost of supplied goods, administration, overhead, and logistics (Neumann, 2003). The cost of goods itself can be expensive, especially pharmaceutical products. The cost of supply can be reduced by negotiating the price of the product but also by procuring refurbished products (Ross & Jayaraman, 2009). Another way to reduce the cost of supply is by reducing stock levels through inventory management. Additionally, purchasing decisions will directly affect inventory levels (S. Kumar et al., 2008). One of the challenges in procurement and inventory management is handling variability in demand, making it difficult to achieve low or no stock levels. By collaborating and sharing information in the supply chain, uncertainty in demand can be reduced, leading to improved customer service levels or reduced inventory levels. Collaborative solutions such as Planning, Forecasting and Replenishment (CPFR), JIT and VMI use information sharing through information systems to create transparent and visible demand patterns (Holweg, Disney, Holmström, & Småros, 2005). Studies have assessed different collaborative solutions for healthcare supply chains. Both VMI solutions and JIT solutions have been found suitable for healthcare logistics. E.g. Mustaffa and Potter assessed vendor managed inventory (VMI) and JIT for Malaysian hospitals and found that VMI was preferable due to poor infrastructure, the distance between clinics, and the high number of delivery points (Mustaffa & Potter, 2009).

Others have found JIT to be a viable solution for hospitals (Jarrett, 1998; Pan & Pokharel, 2007). This paper focuses on process management rather than purchasing and inventory management.

Use and Assessment of Technologies in Healthcare Logistics

In addition to information systems, the use of track and trace technologies can also improve purchasing decisions and reduce costs by lowering inventory (S. Kumar et al., 2008). Thus, technologies can be a means to achieve more efficient processes (Hammer, 1990; Jimenez et al., 2012; C. A. Voss, 1988). Different types of technologies have been implemented in healthcare logistics; these technologies include RFID (Chan, Choi, & Hui, 2012; Ferrer et al., 2010; Fosso Wamba, Anand, & Carter, 2013; Gastaldi, Mangiaracina, Miragliotta, Perego, & Tumino, 2015; A. Kumar & Rahman, 2014; S. Kumar et al., 2008; Qu, Simpson, & Stanfield, 2011; Romero & Lefebvre, 2015; Wang, Chen, Ong, Liu, & Chuang, 2006; Yao, Chu, & Li, 2012), barcodes (S. Kumar et al., 2008; Romero & Lefebvre, 2015), mobile devices (Granlund & Wiktorsson, 2013; Siau & Shen, 2006), ERP-systems (Jenkins & Christenson, 2001; Stefanou & Revanoglou, 2006; Woodside, 2007), MRP-systems (Steinberg, Khumawala, & Scamell, 1982), CPFR (S. Kumar et al., 2008; Lin & Ho, 2014), EDI (Spinardi, Graham, & Williams, 1997; Woodside, 2007), pneumatic tube systems (Al-Riyami et al., 2014; Bakken, 2012; Granlund & Wiktorsson, 2013; Jørgensen et al., 2013), Automated Guided Vehicles (AGVs) (Bakken, 2012; Granlund & Wiktorsson, 2013; A. Kumar & Rahman, 2014; Landry & Philippe, 2004), robotics (Takahashi, Suzuki, Shitamoto, Moriguchi, & Yoshida, 2010), conveyor systems (A. Kumar & Rahman, 2014; Markin, 1994), and automated inventory systems (Bakken, 2012). Overall, the identified technologies can be divided into three groups: 1) track and trace technologies, 2) planning and forecasting technologies, and 3) transport technologies. The technologies considered in this paper are the track and trace technologies.

The technologies used in health logistics as identified in literature are mainly assessed by identifying the benefits of the technology, e.g. (Anand & Wamba, 2013; Ferrer et al., 2010; Gastaldi et al., 2015). Ferrer studied the benefits of RFID across several industries and identified four benefits that were valid for all cases in the study. Thus, some of the identified benefits are industry specific. Literature tends to focus on the evaluation of a single technology, e.g. (Fosso Wamba et al., 2013; Yao et al., 2012), although some studies evaluate two technologies, e.g. (Chan et al., 2012; Romero & Lefebvre, 2015). This paper seeks to identify the decision criteria that are specific to healthcare logistics and that enable the assessment of several technologies.

Other decision criteria than the benefits of a technology may be relevant for assessing a technology. Healthcare logistics should not only be viewed as a means for achieving savings for logistical processes but also as having a more strategic role by supporting the clinical organization to achieve more productive clinical processes (Landry & Philippe, 2004). Decisions in healthcare logistics such as technology assessment should therefore not only be based on financial criteria but also strategic considerations. Furthermore, technologies will often be introduced to improve process performance (Hammer, 1990; Jimenez et al., 2012; C. Voss, Tsikriktsis, & Frohlich, 2002), thus expected process performance should influence the assessment of technologies (Gastaldi et al., 2015), in order to reflect the goals and strategy of the organization (Brewer & Speh, 2000). Due to the multidimensional nature of logistics, it is necessary to measure more than one performance indicator when measuring the performance of a logistical process (Chow, Heaver, & Henriksson, 1994). Thus technologies should be assessed based on several criteria, including benefits of a technology and expected performance.

Performance measurement can provide a platform for improving process performance (Neely et al., 2005). A principal-agent problem occurs when a) goals differ between the principal and agent and b) information and verification of behavior is difficult (Kathleen M. Eisenhardt, 1989). Performance measurement can provide information that reduces information asymmetry between the principal and the agent. Principal-agent theory is used in this study to assess how different technologies affect data validity in the data capturing process.

Multiple criteria decision methods can include criteria that are both quantitative and qualitative in nature (T. L. Saaty, 2004a). There are several multiple criteria decision methods that can be used to assess alternative scenarios. Health Technology Assessment (HTA) is a widely used assessment method within healthcare. However, HTA focuses on solving a health problem and on improving the quality of life (WHO, 2015). Therefore, the HTA is not relevant for assessing track and trace technologies in healthcare logistics, where the aim is to provide more efficient and effective logistical processes. A simple multiple decision criteria method is weighted factor analysis, which has been used for assessing technologies in healthcare logistics (Jørgensen, 2013). A more sophisticated method is Analytic Network Process (ANP), which allows for a quantitative comparison of different solutions based on individual judgment or measurement of identified decision criteria. A special case of ANP is the Analytic Hierarchy Process (AHP), where the decision criteria are independent of each other (T. L. Saaty, 2004a, 2004b; T. Saaty & Vargas, 2006). AHP has been used to assess logistics performance (Korpela & Tuominen, 1996) and to identify critical success factors for introducing CPFR in healthcare (Lin & Ho, 2014). This paper does not focus on a specific quantitative method, but provides a set of decision indicators to which the quantitative methods can be applied.

METHODOLOGY

In this section, the research objectives, research design, collection of data, data analysis, and research quality are described for the study.

Aims and Objectives

The aim of this study is to develop a decision support tool based on an investigation of the overall RQ, which focuses on logistical healthcare processes. In this study, a hospital cleaning process will represent a logistical healthcare process. The overall RQ is answered through a set of sub questions (SQs) which all investigate the hospital cleaning process. The SQs will address different aspects of the decision indicators to be defined for the overall RQ. Management of the hospital logistics department in the case study hospital seeks to improve the performance of the hospital cleaning process, and technologies are a means to achieving this (Hammer, 1990; Jimenez et al., 2012; C. A. Voss, 1988). Which technology to choose will therefore depend on the expected performance of the process. The decision indicators for assessing technologies in healthcare logistics should reflect the performance indicators used to assess performance. Process performance consists of an efficiency and effectiveness aspect; effectiveness relates to reaching a goal, whereas efficiency relates to the economic use of resources (Gleason & Barnum, 1982; Mentzer & Konrad, 1991). Aiming to reach organizational goals will therefore improve process effectiveness and consequently process performance. Studies show that setting clear, specific and particularly challenging goals leads to increased performance. Thus, challenges and goals are closely related, and the more challenging a goal is, the higher the level of performance will be (Locke & Latham, 2002; VandeWalle, Cron, & Slocum Jr., 2001). Challenges and goals are therefore addressed in SQ1 because addressing challenges and setting goals will lead to improved process performance. Similarly, performance indicators are addressed in SQ2 because they reflect performance of a process. Lastly, risk factors affecting data validity are addressed in SQ3 to include the purpose of the technology in the decision process, i.e. to provide valid data. These risk factors relate to informational risks, e.g. capturing and use of data as well as access to key information (Cavinato, 2004), or system risks, e.g. information system breakdowns (Tummala & Schoenherr, 2011). The results from SQ1-SQ3 lead to SQ4 where the final decision indicators used for assessing technologies to measure process performance are identified. The SQs investigated in this study are as follows:

SQ1: *What are the challenges and management goals for a hospital cleaning process?*

SQ2: *How can performance indicators measure process performance of a hospital cleaning process to address challenges and help achieve management goals?*

SQ3: *What are the risk factors affecting data validity for technologies capturing performance data in the hospital cleaning process?*

SQ4: *Which decision indicators should be used to assess technologies capturing performance data in a hospital cleaning process?*

Research Design and Data Collection

This study is a qualitative study within the field of operations management. A single case study design was chosen because it provides an in-depth understanding of a problem and is well suited for answering "how" questions (K. M. Eisenhardt, 1989; Yin, 1994). Furthermore, case studies are suitable for investigating research questions within the theoretical field of operations management (McCutcheon & Meredith, 1993; C. Voss et al., 2002). The case study method has also been widely used within healthcare logistics, e.g. (Granlund & Wiktorsson, 2013; A. Kumar et al., 2008; Pan & Pokharel, 2007; Wang et al., 2006). The case study investigated in this paper is a study of the hospital cleaning process at a public Danish hospital. The hospital cleaning process has mostly been treated in literature to investigate the methods for cleaning as well as methods and indicators for assessing cleanliness (Al-Hamad & Maxwell, 2008; Dancer, 2004; Griffith, Cooper, Gilmore, Davies, & Lewis, 2000; White, Dancer, & Robertson, 2007). This paper takes a slightly different approach. The study investigates how the hospital cleaning case can be used to identify decision indicators for assessing technologies that capture performance data. Although cleaning at a hospital is not considered a traditional logistical process, it was identified in the literature review as a logistical process less treated in literature. The process contains some logistical elements. First, the service of cleaning is *distributed* across the hospital. Secondly, the technologies investigated are technologies commonly used within *supply chain management* and *logistics*, such as RFID and barcodes (Ramanathan, Ramanathan, & Ko, 2014).

The case study hospital is a public Danish hospital in the greater Copenhagen area with room for approximately 700 inpatients at a time. The hospital covers many medical areas but specializes in cancer treatments and also holds a large mother and child facility. Furthermore, the hospital treats almost 500,000 outpatients a year and has an emergency department that treats around 70,000 patients a year. The case study hospital was chosen because of 1) the accessibility to data and 2) the relatively large size of the hospital, which accentuates the challenge of overseeing a large number of cleaning personnel within an extensive area.

Data for the hospital cleaning case was collected over a five month period from October 2014 to February 2015 following a case study protocol. During the case study, 20 interviews were carried out, the cleaning process was observed, and several documents were collected. Interviews were carried out with managers and supervisors of the logistics and cleaning department at the primary case study hospital. Interview persons from another hospital were interviewed to get insight into how the hospital cleaning process was conducted elsewhere. Furthermore, managers from the central IT department for Danish healthcare and the central Strategy department for hospitals in the region were interviewed to learn about the more strategic aspects of technologies and about performance measurement. The interview persons were selected based on their involvement and knowledge about the hospital cleaning process or about data and performance measurement within the Danish healthcare system. Toward the end of the study, case study results were presented to management of hospital logistics at the primary hospital for respondent validation (Bryman, 2012; Yin, 1994). An overview of the interviews and observations for this case study can be found in Table 1.

The conducted interviews were semi-structured interviews that lasted between ½-1 hour depending on the questions that were covered. The interview questions discussed with the interview persons are listed in Table 2 and are linked to the SQs. The interviews were conducted based on more elaborate interview guides that included more questions.

Table 1
OVERVIEW OF INTERVIEWS

Organization	*Roles of persons interviewed*	*Interviews / observations*
(A) Primary case hospital	Head of hospital logistics	2 interview
	Manager of Cleaning department	3 interviews
	2 supervisors in Cleaning department	2 interviews
	Planning coordinator for cleaning	2 interview
	OR logistical services coordinator	2 interviews
	2 head nurses (Urological and Medical departments)	2 interviews
	Hygiene nurse (Hygiene department)	1 interview
	Observation of cleaning process	1 observation
(B) Other hospital	Manager of Cleaning department	1 interview
	Lean consultant	1 interview
(C) Central Lean and Strategy unit for the hospital region	Lean consultant	1 interview
(D) Central IT department for Danish healthcare	2 heads of IT architecture	2 interviews
	IT platform project manager	1 interview

Table 2
THE RELATION BETWEEN MAIN INTERVIEW QUESTIONS AND RESEARCH SUB QUESTIONS

SQs	*Interview questions*
SQ1	What are the main challenges in the hospital cleaning process?
	What are the main goals for the hospital cleaning process?
SQ2	How could capturing data help solve challenges in the hospital cleaning process?
	How could measuring process performance help solve challenges in the cleaning process?
	What should potential performance indicators measure?
SQ3	How could technology help solve the challenges in the hospital cleaning process?
	Which technologies do you use in the hospital cleaning process?
	Which technologies have you considered to use in the hospital cleaning process?
	What are the risk factors that could affect data validity when capturing data?
SQ4	Which decision parameters would be relevant for assessing technologies to be implemented in the hospital cleaning process?

Analyzing Data to Investigate the Research Questions

Each SQ is addressed in turn to answer the overall RQ. For SQ1, challenges and management goals for the hospital cleaning process were identified by mapping and analyzing the hospital cleaning process. Furthermore, challenges and goals were identified through interviews and discussions with logistics management. In SQ2, performance indicators were developed together with management. The performance indicators were based on the strategy and goals of the organization (Brewer & Speh, 2000). In addition, challenges were included as a basis for the performance indicators because of the close relation between challenges and goals, i.e. overcoming challenges to reach goals (Locke & Latham, 2002; VandeWalle et al., 2001). SQ3 was then investigated to ensure data validity. The process of capturing performance data was analyzed to identify risk factors that affect data validity. The analysis was conducted by assessing the risk factors for different types of technologies. These technologies were identified based on literature and interviews in the case study and included the following: iBeacon, tablet, RFID, barcode, and a portable jobagent. Lastly, a set of decision indicators were identified in SQ4 based on findings from SQ1-SQ3. The identified decision indicators in SQ4 therefore relate to challenges and goals (SQ1), performance indicators (SQ2), and data validity (SQ3). The implications for management were then summarized based on the results.

Validity and Reliability

A case study protocol was developed to plan and guide the research activities. The different strategies adopted for collecting data were interviews and observations, and data from several sources were gathered and analyzed. To validate the findings, respondent validation was carried out by interviewing key informants to ensure construct validity (Bryman, 2012; Denzin & Lincoln, 1994; Yin, 1994). To generalize the findings beyond a context within Danish healthcare logistics, a similar study should be conducted outside of Denmark. The case study does not aim to generalize universally but to find out under which conditions certain outcomes can be predicted (Yin, 1994). Lastly, the reliability of the findings was ensured through colleague review and triangulation (Miles, Huberman, & Saldaña, 2014).

SQ1: IDENTIFYING CHALLENGES AND GOALS

Challenges and goals for the hospital cleaning process are identified in this section. First, the hospital cleaning process is mapped, and each process step is then analyzed in turn to identify challenges and goals in the process. The current hospital cleaning process is fairly simple and can be seen in Figure 1.

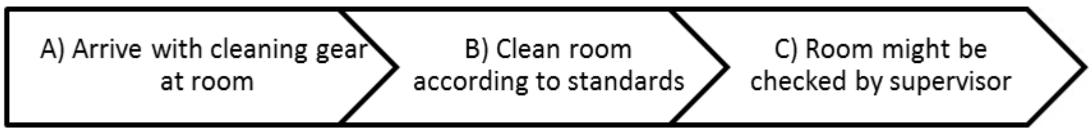


Figure 1 – simple mapping of the current hospital cleaning process

Step A: Arrive With Cleaning Gear at Room

The first process step is the arrival of resources at the place to be cleaned. It is the responsibility of management in the Cleaning department that enough resources are available for the needed cleaning tasks, i.e. *security of supply*. Furthermore, the employees must have the right competences to perform the cleaning tasks satisfactory. One of the challenges experienced by the clinical departments was that the knowledge and quality of cleaning demonstrated by the cleaning personnel during the weekends did not live up to the same standards as on weekdays. This quality issue is related to *employee competences* and translates into *output quality* of the performed tasks.

Step B: Clean Room According To Standards

The cleaning department faces a huge communication and *information management* challenge. It is a challenge to convince people that a room has been cleaned and that it has been done satisfactory. As cleaning personnel will often clean the rooms when no one is in the room, people often mistakenly think that the room has not been cleaned. Only certain cleaning tasks are documented, and for these tasks, only end time and employee ID is registered. There is no *traceability* in the cleaning process and it is not registered nor communicated how much time was spent cleaning, who cleaned it or if it lived up to the necessary quality standards. For those tasks not documented, it is difficult to communicate and convince clinical staff, patients and visitors that the room has indeed been cleaned. Furthermore, the expectations of the clinical departments to the level of cleaning have not been aligned with the quality requirements for cleaning. I.e. even when the Cleaning department lives up to the required quality standards, they are still not satisfied with the result. There is a lack of understanding from the clinical departments as to what level of cleaning is required and what level of cleaning can be expected within a given timeframe. It is therefore difficult for the Cleaning department to communicate that they actually do a good job, and the work of the cleaning personnel is often not recognized.

One part of the communication challenge is to communicate what is already known, i.e. what the Cleaning department already documents. Another part of the challenge is to provide valid data for tasks that are currently not documented. Agreements have been made between the Cleaning department and the clinical departments about the cleaning tasks to be performed. However, it has been difficult to outline these contracts because it is not known how much time is actually spent per room. Part of this problem is that personnel often perform more tasks than written in the agreement. Creating transparency about which tasks have been performed and how much time is spent on them would make it easier to outline contracts and would also help create more trust in the Cleaning department. Creating transparency about tasks would enable better planning and coordination of resources and provide the necessary information for determining process performance. Furthermore, transparency would ensure that the Cleaning department allows enough time for the employee to perform the cleaning task.

Another challenge in the hospital cleaning process is that resources are hard pressed for time. This is partly due to the way resources are planned as only just enough time is scheduled for the employees to clean the rooms. The schedule is based on best practice and past experiences, but no time studies have been carried out. In addition, the cleaning organization faces high sickness absenteeism and difficulties retaining staff, which adds pressure on available resources. The high sickness rates and the issue related to retaining staff can partly be explained by the *employee work conditions* and *employee motivation*. Cleaning is hard work and improving work conditions is in the interest of management and employees to ensure a viable solution for both. Tools, technologies and knowledge about correct ways to perform tasks can alleviate the employees. Another work condition concern is that of monitoring the employees, which could lead to some privacy issues (Chao, Yang, & Jen, 2007; Fisher & Monahan, 2008; Reyes, Li, & Visich, 2012) and the risk of micro management. This concern was expressed by the manager of the Cleaning department:

> *"I would not want to perform micro management and control the individual; I would prefer focusing on the human being and on leading people."*

The work conditions together with the lack of recognition of employee efforts do not provide an environment that encourages employee motivation. The organization has subsequently experienced high rates of employee absence, which has added to the pressure on available resources. Management in hospital cleaning is therefore interested in alleviating resources by eliminating any unnecessary processes.

Step C: Check Quality of Work

The quality of cleaning is important for the hospital as a step to contain any infections and avoid infections from spreading throughout the hospital. One of the goals for the hospital cleaning process is therefore to ensure that the rooms are cleaned sufficiently to help avoid infections from spreading. Thus, the *impact on related processes*, in this case the patient care, is of high importance to the cleaning process.

Summary of Identified Challenges and Goals for the Hospital Cleaning Process

The findings relating to SQ1 have been summarized in Table 3, providing an overview of the challenges and goals in the hospital cleaning process. The identified challenges and goals have been bundled based on similarities. These bundles serve as decision indicators for assessing technologies in a healthcare logistics setting.

SQ2: DEFINING THE PERFORMANCE INDICATORS

Measuring process performance for the hospital cleaning process is an important issue for logistics management at a hospital. Cleaning personnel disperse into all parts of the hospital to clean their designated areas, and it is currently not possible to monitor and check the work of all employees. As the head of logistics pointed out in an interview:

> *"My main concern is that I let all these people [cleaning personnel] loose [in the hospital] and I don't know what they're doing all day… if they're doing what they're supposed to do and if what they are supposed to do is actually the right amount of work… measuring what people do should also be done to ensure they are not overworked and have enough time to perform their tasks."*

Providing information through performance measurement could create transparency about employee performance and the quality of their work (Neely et al., 2005). However, the statement by the head of logistics indicates that creating transparency about performance is not only for the benefit of management and the hospital but also for the employees.

Table 3
CHALLENGES AND GOALS BUNDLED INTO DECISION INDICATORS

Decision indicators	*Challenges*	*Goals*
Security of supply	Scarce resources and difficulties in retaining the resources they have.	Ensuring enough resources to perform cleaning tasks.
Output quality	Cleaning quality differs between weekdays, weekends, and seasons (cleaning quality).	Ensuring quality of work (cleaning quality).
	Valid data not available for performance indicators (data quality).	Ensuring valid data (data quality).
Employee work conditions	Cleaning is hard work. Enough time should be allowed to perform tasks.	Avoiding micro management.
Competence match	Competences are not the same in weekends as on weekdays.	Ensuring same quality of work regardless the day of the week.
Information management	Lacking use of technologies to capture data.	Ensuring enough time is allowed for employees to perform tasks according to cleaning standards.
	Challenges faced with coordinating and prioritizing resources and tasks across teams.	
	Lacking overview of continuous progress in tasks performed.	Being able to determine whether a process is efficient.
	Being unable to show what has actually been done. There is a challenge in assessing and communicating performance, and in aligning	Being able to verify and communicate which tasks have been performed and to what quality level.

	expectations with clinical departments.	
Traceability	Not knowing where employees are and what they are doing.	Being able to assess individual performance.
Employee motivation	Cleaning is hard work and efforts are often not recognized. This has led to lack of motivation and high absenteeism.	Making the job physically easier for employees and ensuring that their efforts are recognized.
Unnecessary process	Resources are hard pressed for time and no unauthorized breaks are allowed. This issue is enhanced by high absenteeism.	Eliminating any unnecessary processes in order to alleviate hard pressed resources.
Impact on related processes	Hospital infections spreading in the hospital.	Provide high quality cleaning and avoid infections from spreading.

Performance indicators should reflect the strategy of the organization and help achieve organizational goals (Brewer & Speh, 2000). To align organizational behavior with strategic goals, central management covering all hospitals in the region had defined the following five performance aspects to be measured: (1) quality, (2) resources, (3) productivity, (4) satisfaction, and (5) service delivery. These aspects of performance measurement are based on the overall strategy of the hospital region and should be traceable down to the individual employee. Based on the five aspects to be measured, a set of performance indicators were developed together with management. These indicators can be seen in Table 4. The performance indicators have been bundled into decision indicators that are aligned with the decision indicators found for SQ1.

In measuring quality (1) of the hospital cleaning process, it is only possible to check the quality of a random sample of rooms. The random sample of rooms is checked according to two quality standards and the share of rooms that passes the quality standards is then used as a quality measure, i.e. *% rooms passed quality check*. Additionally, to provide some quality assurance for the rooms not checked, supporting performance measures were developed. Case study interviews showed that quality and time spent on cleaning are closely related. Software is used to estimate the amount of time needed to clean each room. These norm times are adjusted on a regular basis to best reflect the amount of time needed to clean a specific room. Planning of resources is based on these norm times and the aim of management has been to allocate just enough time for an employee to clean a room at a satisfactory level. Thus, it is estimated that all the allocated time should be used for cleaning the room in order to achieve a satisfactory result. Demonstrating that a certain amount of time has been spent in a room could therefore provide supporting evidence of the level of quality. The suggested performance indicator *norm time/time spent cleaning* is therefore both a productivity measure and a supporting quality measure.

Resources (2) are reflected in the performance indicators by measuring *% sick leave* and *#employees on leave*. As mentioned in the section identifying challenges and goals for the hospital cleaning process, one of the major challenges is that employee absenteeism is high for the department and that employees are hard pressed for time. Management is therefore interested in closely monitoring the availability of resources.

Productivity indicators (3) were developed to reflect how much time was spent on value-adding processes by measuring *norm time/time spent cleaning*. *Norm time/time spent cleaning* can also be viewed as value-added time. To measure the efficiency of the individual employee, *#planned cleanings/employee* was chosen as an indicator.

Satisfaction (4) was already assessed in a yearly report though a survey sent out to all departments in the hospital. This report was a qualitative study and not a quantitative measure as such, and management wished to keep it that way.

Finally, for service delivery (5), two indicators were selected. To make it easier to outline contracts with clinical departments and communicate about performed tasks, *% delivered of planned* was chosen as an indicator. *% delivered of planned* indicates how many of the promised tasks were actually finished. Another aspect of service delivery interesting to management was the *lead time* for acute tasks. Compared to the planned tasks, these tasks were time sensitive and timely delivery imperative.

Table 4
PERFORMANCE INDICATORS BUNDLED INTO TOPICS

Decision indicators	*Performance indicators*
Output quality	% rooms passed quality check Norm time/time spent cleaning (supporting indicator) Experienced service report
Value-added time	Norm time/time spent cleaning (primary indicator)
Security of supply	# finished tasks / promised % delivered of planned
Lead time	Lead time
Unnecessary process	# planned cleanings / employee % sick leave # employees on leave
Traceability	All performance indicators should be traceable to the individual person.

SQ3: TECHNOLOGIES, RISK FACTORS, AND DATA VALIDITY

SQ3 investigates the process of capturing data within hospital cleaning. To measure the performance indicators identified in the previous section, it is necessary to capture different types of data in the process. In the following, each step of the data capturing process within hospital cleaning is analyzed to identify risk factors affecting data validity. The risk factors are summarized in Table 5 and bundled into decision indicators.

The Process of Capturing Data within Hospital Cleaning

Technologies would be needed to enable measurement of the developed performance indicators for the hospital cleaning process. The alternative would be to manually register the data points in the process, which would be time consuming. Figure 2 shows an example of how data could be captured in the hospital cleaning process, in this case by registering start and end time of the cleaning process.

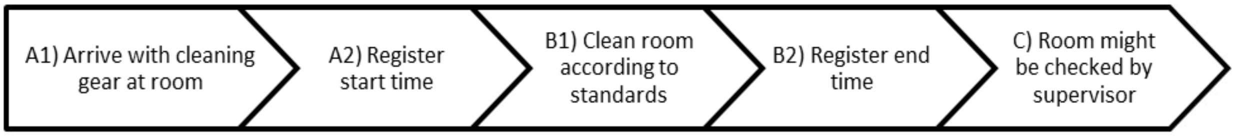


Figure 2 - mapping example of registering data in the hospital cleaning process

Five technologies were assessed for the hospital cleaning process for capturing performance data. These technologies were RFID, barcodes, tablets/apps, iBeacons, and portable jobagents. The hospital already uses some of these technologies such as barcodes, tablets and portable jobagents, and the technology that the Cleaning department chooses could potentially be used by other departments. E.g. RFID could be used to track doctors, patients and medical equipment. Thus, taking into consideration that others may benefit from the technology suggests an element of *future proofing*. Future proofing means that the chosen technology is also likely to be used by the hospital in the future and that it will not become obsolete any time soon.

Step A: Arrive At the Room and Register Start Time

The first steps of the process would be for the employee to arrive at the room to be cleaned (step A1) and then register the starting time (step A2). This registration would be done electronically, but not necessarily automatically. For the RFID and iBeacon technologies, this registration would happen automatically. Data such as room number, time stamp, and personnel ID could be registered. However, for other technologies, some manual effort would be needed to register data. For barcodes, the employee would have to scan a barcode such as one on an ID card, which would then register room number, time stamp, and personnel ID. Lastly, using tablets and portable job agents means that the employee would have to identify the task, i.e. room to be cleaned, on the device. Upon identification on the device, time stamp and personnel ID would be registered.

The solutions with tablets and job agents differ from the other solutions in that the registration does not require or ascertain the presence of an employee in a given location at a given point in time. Thus, from an agency theory point of view, it is not possible to ascertain whether the employee was present at the location at the given point in time, which means there is information asymmetry. Traceability will therefore reduce information asymmetry. Furthermore, the registration requires an effort of the employee to actively make a registration. Risk of forgetting to register data means there is a risk that data validity will be impaired if data is not registered automatically. I.e. the degree of automation is important in ensuring data validity. In addition, if data is not registered automatically, it might not be registered in a consistent manner, which would also increase the risk of mistakes. If the employee has to actively make a registration, this may not happen at the same point in the process every time. However, if the registration is automated, the risk of mistakes would be reduced and consistency would be ensured. Therefore, the degree of automation is closely related to *risk of mistakes* and *consistency*. Conversely, a higher degree of automation also means that the ability to capture data is fully dependent on the technology and that any downtime and maintenance may disrupt data capturing and thereby affect data validity. Lastly, for the technology to capture data, the employees must be able to use the technology, i.e. the technology should be easy to use, and the employees should possess the necessary competences.

The employee may not see it as in his or her interest to measure performance, especially personal performance. The goals of the employee may therefore differ from the goals of management. Viewing the registration task from an agency theory perspective; if the goals of management are not the same as those of the employee, and if it is difficult to obtain information about the employee's behavior, an agency problem occurs. Unless there is a motivation for the employee to make the registration, there is a risk that the employee may neglect or forget to do so. It is important to note that monitoring individual employee performance will not only enable management to address poor performance but also to recognize good performance.

Step B: Clean the Room and Register End Time

For step B2, the same risks affect data validity as identified for registering start time in step A2. Only step B1 will therefore be analyzed in the following. One of the challenges mentioned earlier is the differing level of quality between weekends and weekdays. The cleaning personnel during the weekends does not include experienced employees. Weekend personnel is often be people not working full time within the cleaning field. The less experienced employees are therefore not as knowledgeable and skilled as the more experienced employees. This lack of knowledge and skill has led to quality issues during the weekends. One way of addressing this challenge is to supply the employee with the correct knowledge when needed, thus helping the employees gain the needed *competences*. This could be done by providing videos and illustrations of how a certain task should be performed, e.g. using iBeacons or tablets.

Step C: Check Quality of Work

In the hospital cleaning case, a number of randomly selected rooms would be checked by a supervisor. The supervisor would follow a check list to assess the room according to two Danish quality standards (INSTA 800 and DS2451-10). The assessment would be noted on a physical template and later typed into a spreadsheet on the office computer. The extra process in documenting and re-documenting data is essentially an unnecessary process that increases the risk of mistakes and puts data validity at risk. Furthermore, the extra step also means there may be a shift in who performs the process, i.e. a competence shift.

Table 5
SUMMARY OF IDENTIFIED RISK FACTORS AFFECTING DATA VALIDITY

Decision indicators	***Description of risk factors identified in the process analysis***
Future proofing	Ensuring that the technological solution capturing data will persist in the hospital to provide valid data in the future.
Traceability	Ascertaining time and location of the employee that performed a task is necessary to enable to assure that the employee had been at the location.
Degree of automation	Automating the process of registering data reduces the risk of mistakes in the way data is captured. It also ensures that data is captured in the same way and prevents employees from neglecting or forgetting data registration.
Risk of mistakes	Degree of automation is closely related to the risk of mistakes in data capturing. Incorrect registrations lead to incorrect and invalid data.

Table 5 (continued)
Summary of identified risk factors affecting data validity

Decision indicators	*Description of risk factors identified in the process analysis*
Consistency	Degree of automation and a reduced risk of mistakes lead to higher consistency in data. Inconsistency in data renders data incomparable.
Features and ease of use	If data is not captured automatically, one of the pre-requisites for enabling data registration is that employees are able to operate the technology. Ease of use makes it more likely that employees can operate the technology.
Competence match	Together with ease of use, ensuring that employees have the right competences will increase the likelihood of employees correctly operating the technology.
Employee motivation	Ensuring ease of use and the right competences are pre-requisites for enabling the use of technologies that are not automated. The next challenge is to ensure that the employee is then motivated to actively register data.
Unnecessary process	Unnecessary processes such as double entry of data increases the risk of incorrect data registration from one registration to another.
Competence shift	If double entry of data is handed over from one employee to another, the risk of incorrect data registration increases due to the risk of miscommunication.

SQ4: DEFINING THE DECISION INDICATORS

Defining Decision Indicators Based On the Case Study Analyses

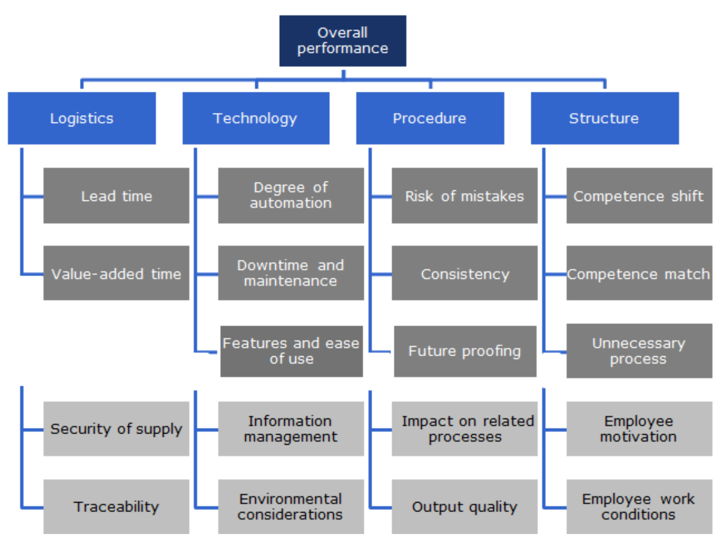
As a result of the analyses conducted for SQ1-3, 18 decision indicators (Table 6) have been identified based on the hospital cleaning case. The purpose of the decision indicators in the framework is to enable assessment of alternative solutions for a logistical healthcare process.

To make the list of indicators more coherent and transparent, the 18 decision indicators were structured into logical categories. Commonalities were identified between decision indicators, and the decision indicators were grouped into four categories: Logistics, Technology, Procedure and Structure. Logistics refers to logistical activities as defined in the literature review. Technology refers to the track and trace technologies as found in the literature and in discussions with management in the case study. Procedure refers to the formalized processes in healthcare logistics, e.g. standard operating procedures. Finally, Structure refers to the organizational structure in a healthcare setting. The 18 decision indicators structured into the four categories form the developed decision framework in this case study. The framework is illustrated in Figure 3.

Table 6
OVERVIEW OF IDENTIFIED DECISION INDICATORS AND THE SQS THEY WERE IDENTIFIED FOR

Decision indicators	*SQ1: Challenges/goals*	*SQ2: Performance*	*SQ3: Risks*
Security of supply	Challenges and goals		
Output quality	Challenges and goals	Performance indicators	
Competence match	Challenges and goals		Risk factors
Information management	Challenges and goals		
Traceability	Challenges and goals	Performance indicators	Risk factors
Employee work conditions	Challenges and goals		
Employee motivation	Challenges and goals		Risk factors
Unnecessary process	Challenges and goals	Performance indicators	Risk factors
Impact on related processes	Challenges and goals		
Value-added time		Performance indicators	
Lead time		Performance indicators	
Future proofing			Risk factors
Degree of automation			Risk factors
Risk of mistakes			Risk factors
Consistency			Risk factors
Downtime & maintenance			Risk factors
Features and ease of use			Risk factors
Competence shifts			Risk factors

Figure 3
DECISION INDICATORS FOR ASSESSING TECHNOLOGIES IN HEALTHCARE LOGISTICS



Implications for Management When Assessing Track and Trace Technologies

The implications for management of the results in this paper are presented in the following. A list of decision steps is proposed for selecting track and trace technologies to measure performance indicators within healthcare logistics. In the section analyzing SQ1, a list of challenges and goals were identified. Subsequently, a set of performance indicators were developed in SQ2. This paper considered the selection of technologies to measure these performance indicators. The combination of technology and data point to be measured creates a certain level of data validity, i.e. some technologies produce more valid data than others. In the investigation of SQ3, the risk factors affecting data validity were identified.

The financial aspect of selecting a technology is not covered by the 18 identified decision indicators identified in this paper. The main part of the Danish healthcare system is public, and funds are limited. This means that funding for logistical investments is often scarce as clinical investments are prioritized. Most organizations would not invest a large amount of money without calculating a business case, and the financial aspect of investing in technologies should therefore be considered alongside the identified decision indicators in the framework. In the process of selecting a new technology to invest in, the organization will have to secure the funds for the investment. Financial considerations could have practical implications for the choice of performance indicators and track and trace technologies. The benefits of the investment should outweigh the costs, and one of the benefits is the amount of data that will be provided by the technology. A certain number of data registrations above a level of some critical mass would therefore be a prerequisite for a profitable business case. Another financial aspect to consider is that one technology may not fit all. Thus, it may be necessary to invest in more than one technology or reduce the number of indicators to be measured. Although performance measures should be governed by the overall strategy of the organization (Brewer & Speh, 2000), the economically feasible technologies may not enable measurement of the preferred performance indicators. Steps should therefore be taken to accommodate any financial limitations. Based on the analysis presented in this section, the following decision steps are proposed for selecting technologies to measure process performance in healthcare logistics:

1. Select performance indicators based on goals, challenges, and strategy
2. Ascertain critical mass for data registration
3. Compare the 18 decision indicators for each of the potential technological solutions
4. Assess data validity for data-technology combinations based on the identified risk factors
5. Compare data validity with the cost of investment in technology
6. Determine feasible technological solutions from a financial perspective
7. Adjust performance indicators if necessary

The third decision step comparing the 18 decision indicators is one of the most extensive steps in the decision process. The comparison could be done qualitatively or quantitatively by using quantitative methods such as AHP or ANP.

DISCUSSION

Most of the literature on assessing technologies in a logistics setting tends to focus on the benefits of a specific technology, e.g. (Anand & Wamba, 2013; Yao et al., 2012). Some of the benefits identified in literature are generic across industries while others are specific to a particular industry (Ferrer et al., 2010). The developed framework focuses on decision indicators specific to a healthcare logistics context. In addition, the framework proposed in this study is suitable for assessing different types of track and trace technologies based on a set of decision indicators. The decision indictors can be evaluated for each technological solution and assesses the solution from a process performance perspective. Thus, the decision indicators in the framework do not only take the benefits of the specific technology into account, but provides a more context specific decision support tool. The context specificity is not only provided by assuming a process perspective, but also by considering effects outside of the process such as *impact on related processes*. Thus, a systems perspective is assumed, providing a more holistic view of the hospital. In addition, the type of hospital and the financial situation of the hospital may influence preferences of management. These preferences can then be expressed in the decision framework by letting management evaluate each decision indicator.

Some of the decision indicators resemble the benefits of technology adoption found in literature. E.g. Ferrer also identified automation as a benefit / decision criterion (Ferrer et al., 2010). The benefits identified by Ferrer relate to operations strategy objectives and are thus limited to the operations side of the hospital. Although the logistical processes considered in this paper are operations oriented, the decision criteria need not be limited to this. The strategy and organization of the hospital as a whole, especially the clinical departments, should also be taken into consideration (Landry & Philippe, 2004).

The main RQ was answered through four underlying SQs, which were each answered through three different analyses. Furthermore, implications for management were summarized in 7 decision steps proposed for assessing technologies in healthcare logistics. Findings in this paper are limited to a healthcare logistics context and should be validated for other contexts and settings outside of Denmark. The literature review revealed a lack of literature investigating specific healthcare logistics processes. This study is limited to a single case study of the hospital cleaning process, and similar studies of other healthcare logistics processes should be conducted. Based on the literature review, a gap in technology assessment for logistical healthcare was identified, and was subsequently investigated in this study. The developed framework showed similarities to existing literature while at the same time contributing with new knowledge on technology assessment.

CONCLUDING REMARKS

The framework proposed in this study has provided a set of decision indicators for assessing different types of track and trace technologies. The identified decision indicators were identified based on 1) challenges and goals, 2) performance indicators, and 3) risk factors affecting data validity. In addition to the decision indicators provided in this study, each of the three aspects are interesting in their own right and can be used separately. E.g. to identify main challenges and goals of a process for process improvement purposes, developing performance indicators for a process improvement initiative, and lastly assessing data validity for different technologies. The main challenges identified in the case study were related to information management. The challenge of information management included creating transparency about which tasks had been conducted as well as the performance on quality and productivity. Being able to measure performance indicators would support better communication to the clinical staff, patients, and visitors. A set of performance indicators was proposed to enable communication of performance and to ensure that the cleaning tasks had been performed, and that they had been done satisfactory. To ensure quality of cleaning, productivity measures were developed to support the quality measures. This is to ensure that cleaning personnel has spent enough time in the room to clean it at a satisfactory level. This measure is especially important for rooms that have not been quality checked. Finally, risk factors affecting data validity were identified. The main risk factors relate to traceability, degree of automation, features and ease of use, and employee motivation. The technology used to capture data in the process will affect data validity, and data validity can be assessed for each technology by evaluating the identified risk factors. Furthermore, the feasible choice of performance indicators may be affected by the choice of technology.

This paper contributes with a set of decision indicators for assessing track and trace technologies in a healthcare logistics setting. The decision indicators form a framework that serves as a decision support tool for management in healthcare logistics. The framework is structured around four constructs: Logistics, Technology, Procedure, and Structure. In practice, the framework can be used either qualitatively by comparing each decision indicator for different scenarios and/or by applying a quantitative method such as AHP or ANP.

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PAPER 4

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Benchmarking healthcare logistics processes – a comparative case study of Danish and US hospitals

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Logistics processes in hospitals are vital in the provision of patient care. Improving healthcare logistics processes provides an opportunity for reduced healthcare costs and better support of clinical processes. Hospitals are faced with increasing healthcare costs around the world and improvement initiatives prevalent in manufacturing industries such as lean, business process reengineering and benchmarking have seen an increase in use in healthcare. This study investigates how logistics processes in a hospital can be benchmarked to improve process performance. A comparative case study of the bed logistics process and the pharmaceutical distribution process was conducted at a Danish and a US hospital. The case study results identified decision criteria for designing efficient and effective healthcare logistics processes. The most important decision criteria were related to quality, security of supply and employee engagement. Based on these decision criteria, performance indicators were developed to enable benchmarking of logistics processes in healthcare. The study contributes to the limited literature on healthcare logistics benchmarking. Furthermore, managers in healthcare logistics are provided with a list of decision parameters relevant for designing and benchmarking processes.

Keywords: hospital logistics; benchmarking; performance measurement; bed logistics; pharmaceutical distribution; business process management

Introduction

Healthcare systems across the world face the challenge of increasing costs due to an ageing population and more sophisticated treatments (OECD, 2015; Saltman & Figueras, 1997; WHO, 2010). At the same time, patients are demanding high-quality care at lower expenses. As a result, process improvement initiatives prevalent in manufacturing industries have seen an increase in use in healthcare, such as lean (De Souza, 2009; Joosten, Bongers, & Janssen, 2009), just-in-time (Heinbuch, 1995; Whitson, 1997), Six Sigma (Lifvergren, Gremyr, Hellström, Chakhunashvili, & Bergman, 2010; Taner, Sezen, & Antony, 2007), TQM (Chen, Chen, Wu, & Lin, 2004; Kanji & Moura e Sá, 2003), benchmarking (van Lent, de Beer, & van Harten, 2010; van Lent, Sanders, & van Harten, 2012), business process reengineering (BPR) (Bertolini, Bevilacqua, Ciarapica, & Giacchetta, 2011; Ham, Kipping, & McLeod, 2003), and automation (Falan & Han, 2011; Poulymenopoulou, Malamateniou, & Vassilacopoulos, 2012). Studies have shown that benchmarking is amongst the most implemented managerial approaches in hospitals along with TQM, care pathways, BPR, and lean management (van Lent et al., 2012; Yasin, Zimmerer, Miller, & Zimmerer, 2002). However, expected goals are far from always achieved

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upon implementation and hospitals are left to their experience and judgement in selecting an improvement approach (van Lent et al., 2012; Volland, Fügener, Schoenfelder, & Brunner, in press). Thus, there is a need for more rigorous studies on process redesign in healthcare (Elkhuizen, Limburg, Bakker, & Klazinga, 2006), particularly on how to select suitable operations management best practices for implementation (Sousa & Voss, 2008; Volland et al., in press).

Logistical support processes in hospitals amount to over 30% of hospital expenditure, half of which could be eliminated through benchmarking and best practice implementation (Aptel, Pomberg, & Pourjalali, 2009; Mckone-Sweet, Hamilton, & Willis, 2005; Poulin, 2003). Thus, logistical activities in hospitals provide significant opportunities for cost reductions in healthcare. Logistical activities include activities such as inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfilment, logistics network design, inventory management, supply/demand planning, and management of third-party logistics services providers (Council of Supply Chain Management Professionals, 2015).

A hospital survey on the success of different managerial approaches, for example, benchmarking, TQM, and BPR, revealed that half of the hospitals had not achieved their goals upon implementation. Furthermore, no approach seemed to outperform the others (van Lent et al., 2012). The approach that best fits an organisation is highly dependent on the context (Sousa & Voss, 2001, 2008). Thus, Pan and Pokharel (2007) describe a set of parameters that characterise logistics activities in Singapore hospitals in order to identify improvement potential, and Aronsson, Abrahamsson, and Spens (2011) identify what is important to consider when developing a supply chain in healthcare. Similarly, this paper identifies decision criteria to be considered when designing logistics processes within healthcare. The first research question addressed in this paper is therefore:

> *RQ1*: Which decision criteria are consistent between Danish and US hospitals for designing efficient and effective healthcare logistics processes?

Efficiency is input oriented and is concerned with the economic use of resources, whereas effectiveness is output oriented and is concerned with achieving goals (Mentzer & Konrad, 1991; Neely, Gregory, & Platts, 2005). To enable process comparison, a benchmarking approach is applied. Benchmarking consists of a practice and a metric component (Camp, 1989b; Voss, Åhlström, & Blackmon, 1997), but a benchmarking study does not necessarily include both (Hanman, 1997; Mayle, Hinton, Francis, & Holloway, 2002). Benchmarking studies can be divided into a three-step approach: (1) determining current performance level, (2) comparing performance with best practice, and (3) planning how to reach or exceed best practice (Hanman, 1997). The second research question enables the first two steps:

> *RQ2*: How can performance measures be defined based on the identified decision criteria in order to benchmark healthcare logistics processes?

This paper aims to develop a method for benchmarking logistics processes in hospitals that allows managers to select the process design that best fits their organisation. A comparative case study of a Danish and a US hospital was conducted investigating the bed logistics process and pharmaceutical distribution process. The paper applies a mixed-methods approach and combines the use of qualitative and quantitative data to increase the validity of the study. Thus, interviews, observations, and documents are combined with quantitative assessments of the decision criteria by the involved decision-makers. The study draws on the literature from business process management (BPM), performance measurement, and benchmarking.

Literature review

Bed logistics and pharmaceutical distribution in hospitals

The two process types investigated in this paper are the bed logistics process and the pharmaceutical distribution process. Pharmaceutical logistics is considered one of the most important logistics processes in hospitals, whereas the bed logistics process tends to rank lower in the minds of decision-makers (Kriegel, Jehle, Dieck, & Mallory, 2013). However, the bed logistics process is closely related to the vital patient flow as the bed flow is triggered by and partly follows the flow of the patient. Problems identified in patient flow logistics include patient flow variability caused by poor allocation of resources, lack of coordination between pipelines and production, and balancing elective and unscheduled demand (Villa, Prenestini, & Giusepi, 2014). Optimising patient flow logistics improves quality of care and optimises the use of limited resources (Kriegel, Jehle, Dieck, & Tuttle-weidinger, 2015; Kriegel, Jehle, Moser, & Tuttle-Weidinger, 2016). Better planning of patient admission and assignment could help address the issues in patient flow logistics. At a strategic level, the problem hospitals face is a bed-sizing problem and at an operational level, it is a bed planning problem (Bachouch, Guinet, & Hajri-Gabouj, 2012). At a strategic level, mathematical models and simulation can be applied to calculate bed requirements within a hospital, for example (Utley et al., 2003; Zhu, Hen, & Teow, 2012). At a more operational level, a decision support system using operational research techniques for admission planning and bed assignment could improve bed utilisation, reduce dismissal rates (Bachouch et al., 2012; Schmidt, Geisler, & Spreckelsen, 2013), and reduce the number of crowding beds (Holm, Lurås, & Dahl, 2013). However, such an approach might not capture the complexity that characterises a healthcare system, which could better be captured through simulation models (Holm et al., 2013) or a mixture of the two approaches, for example (Schmidt et al., 2013).

Some studies apply a more process-oriented approach as the one taken in this paper. Thus, Villa, Barbieri, and Lega (2009) suggest a patient-centric redesign of patient flow logistics to improve productivity and quality. Along the same lines, Kriegel et al. (2015, 2016) identify central patient admission, case management, and patient discharge management as most important levers for improving patient flow. Chiarini demonstrates how mapping tools derived from lean, that is, spaghetti charts, value stream mapping, and activity worksheets, can reduce distances travelled and time spent on patient transportation in hospitals (Chiarini, 2013). Furthermore, several authors have investigated the current use of and potential for radio frequency identification (RFID) in healthcare, for example, to track and trace assets such as beds and linen (Kumar & Rahman, 2014; Wamba, Anand, & Carter, 2013; Wamba & Ngai, 2015). Jehle et al. (2015) apply a benchmarking approach to patient transport logistics to identify areas for improvement. Finally, Hastreiter, Buck, Jehle, and Wrobel (2013) conduct a benchmarking study of patient transport in hospitals to identify areas for improvement. Thus, different process improvement tools have been applied and tested for the bed logistics process, including benchmarking.

The second process investigated in this paper is the pharmaceutical distribution process. The current trend of healthcare supply chains is a move towards global supply chains (Privett & Gonsalvez, 2014). However, this results in complex coordination issues of the many agents in the supply chain with often differing objectives (Gebicki, Mooney, Chen, & Mazur, 2014; Shah, 2004).

Several authors have analysed the pharmaceutical supply chain from an operations research perspective by applying mathematical modelling, for example, to optimise timing and batch sizes (Dobson, Tilson, & Tilson, 2015), to reduce product and process waste (Tilson, Dobson, Haas, & Tilson, 2014), and to cope with the complexity in the supply chain due to unpredictable demand and the multiple constraints that have to be taken into account for pharmaceutical products (Jurado et al., 2016).

Given the risk of adverse health effects from pharmaceutical products, the pharmaceutical industry is subject to stringent legislation. Thus, Elleuch, Hachicha, and Chabchoub (2014) analyse a pharmaceutical supply chain from a risk perspective and propose a framework that applies a plethora of quantitative methods for risk assessment and risk mitigation purposes. Furthermore, to reduce medical errors, healthcare providers have started implementing TQM to improve patient safety (Smith & Offodile, 2008). Chen and colleagues provide an example of implementing TQM in a pharmaceutical logistics organisation. The paper describes how TQM methods and tools can be successfully implemented in a healthcare pharmaceutical logistics organisation and identifies four phases of TQM implementation: (1) awareness, (2) storming, (3) norming, and (4) performing. The TQM efforts resulted in cost reductions, sales increase, and low employee turnover (Chen et al., 2004).

Different process reengineering tools have been tested for pharmaceutical supply chains. Pinna and colleagues investigate pharmaceutical logistics flow redesign and the advantages of a unit dose distribution system. In addition to more simplified processes, advantages include reductions in ward stock, pharmacy inventory, medicine cabinet management, and likelihood of errors (Pinna, Carrus, & Marras, 2015). Al-Shaqha and Zairi provide case study examples of how re-engineering pharmaceutical processes can provide more patient-focused care by decentralising pharmacists to be part of the clinical care teams (Al-Shaqha & Zairi, 2000). Papalexi, Bamford, and Dehe (2016) analyse the applicability of lean tools and suggest that implementing a kanban system in the pharmaceutical supply chain will significantly reduce inventory levels and inventory costs, whilst improving the quality of services through waste elimination and a more reliable product flow. Finally, Narayana, Elias, and Pati (2014) analyse the return of pharmaceuticals from a systemic point of view and identify factors impacting the reverse supply chain.

Real-time information enables the management and control of processes. Automated dispensing machines for pharmaceutical products and sterile medical devices provide information on inventory levels at the point of use and can reduce stock-outs and stock levels, improve inventory accuracy, and reduce time spent on inventory management (Bourcier et al., 2016; Gebicki et al., 2014; Rosales, Magazine, & Rao, 2014). Furthermore, track and trace technologies such as RFID and barcodes have received increasing attention in healthcare supply chains (Wieser, 2011; Yazici, 2014). Thus, Chircu, Sultanow, and Saraswat (2014) study the application of RFID in an end-to-end pharmaceutical supply chain and identify benefits such as improved communication of data and information, reduced counterfeiting, and enabled monitoring of the quality of drugs. Romero and Lefebvre investigate how track and trace solutions combining RFID and barcodes can improve a hospital's internal pharmaceutical supply chain. However, according to the authors, little empirical evidence exists on how to improve the internal logistics of pharmaceuticals (Romero & Lefebvre, 2015), suggesting that more studies are needed on this topic.

Benchmarking in hospitals

There is a strong correlation between benchmarking and superior performance (Voss et al., 1997). Benchmarking has been defined as the search for industry best practices that lead to superior performance (Camp, 1989a). Since then, the definition of benchmarking has evolved into 'a management tool that can be defined as the systematic process of searching for best practices, innovative ideas and efficiencies that lead to continuous improvement' (Wong & Wong, 2008, p. 27). Thus, continuous improvement is an important aspect of benchmarking (Alstete, 2008; Dattakumar & Jagadeesh, 2003; Hong, Hong, Roh, & Park, 2012; Wong & Wong, 2008). Gift and Mosel provide a definition of healthcare benchmarking as 'a continual and collaborative discipline, which involves measuring and comparing the results of key processes with the best performers and adapting best practices to achieve breakthrough process improvements in support of healthier communities' (Mosel & Gift, 1994, p. 241). However, best practices can be costly to uncover and may never be identified. A more pragmatic definition of benchmarking is, therefore, 'a continuous, systematic process of measuring products, services and practices against organizations regarded to be superior with the aim of rectifying any performance "gaps"' (Kouzmin, Löffler, Klages, & Korac-Kakabadse, 1999, p. 123).

Lega, Prenestini, and Spurgeon (2013) found that high-performing hospitals are characterised by management that is oriented towards multidimensional performance, expresses clear goals, and utilises management tools. Research on performance indicators and benchmarking in healthcare mainly relates to not only patient care, for example, care delivered in hospitals, primary care, patient experience, patient safety and mortality (Klazinga, Fischer, & ten Asbroek, 2011), and the efficiency of physicians, but also hospital efficiency (Hussey et al., 2009). Almost half of healthcare efficiency measures in the literature are ratios consisting of input and output metrics, the other half being econometric or mathematical programming methods (Hussey et al., 2009). One such mathematical programming method is Data Envelopment Analysis (DEA), which uses linear programming to identify an efficiency frontier based on observations of efficiency measures. This method has been used to benchmark hospital performance by comparing the efficiency of specific services, departments, or entire hospitals (Chang, 1998; Lambert, Min, & Srinivasan, 2009; Nayar, Ozcan, Yu, & Nguyen, 2013; Ozcan, 2008). However, due to the small sample size of case organisations in this study, the DEA method was not applied, as the main strength of the method lies in the ability to compare across organisations of different sizes.

The provision of healthcare involves multiple actors and creates a complex environment for decision-making (de Vries & Huijsman, 2011). Hassan demonstrates how performance in healthcare can be measured based on the perception of multiple stakeholders to enable a comprehensive evaluation of business excellence. The engaged stakeholders include patients, staff, accreditation bodies, and government authorities (Hassan, 2005).

Xiong and colleagues propose a measurement instrument that enables benchmarking of quality management practices and the identification of best practices in hospitals. The instrument consists of nine constructs relating to (1) top management leadership, (2) quality policy, (3) role of the quality department, (4) training, (5) process management, (6) customer focus, (7) employee relations, (8) quality information and analysis, and (9) supplier quality management (Xiong, He, Ke, & Zhang, 2015). These constructs could easily be applied to logistics practices in a hospital and some of the constructs can be characterised as logistics or supply chain measures.

In some healthcare systems, the need for benchmarking lies not only with the provider, but also with the consumer, that is, patient. In a study by Van der Wees and colleagues, performance measurement in the healthcare systems of Massachusetts and the Netherlands is compared. The authors identify three main challenges related to comparing performance: first, to create quality measures that can be used both at the clinical quality improvement level and at the aggregate accountability level; second, to establish a set of standardised quality measures and avoid information overload; and third, to present easily understandable and customised information to consumers as decision support (Van der Wees et al., 2014).

Some benchmarking studies in healthcare take a different approach than the typical measures related to care and hospital efficiency. For example, Sargiacomo uses internal benchmarking to compare staff motivation and satisfaction between wards and health districts of the same healthcare provider. A benchmark amongst the departments was identified based on staff ratings of a set of indicators reflecting staff motivation and satisfaction. Areas for improvement were subsequently identified and recommendations to fill the performance gap suggested (Sargiacomo, 2002).

Identifying best practices and benchmarking healthcare logistics processes

A structured literature review by Dobrzykowski and colleagues established that the design of healthcare delivery systems was one of the most prevalent topics in the healthcare supply chain management (SCM) and operations management literature. However, measurement of services was one of the least researched topics (Dobrzykowski, Deilami, Hong, & Kim, 2014). How to measure performance in hospital logistics is, therefore, a major research opportunity in the field of healthcare logistics (Volland et al., in press). Hastreiter and colleagues identified 19 articles relevant to benchmarking logistics services in hospitals and found that the topic has gained importance in recent years. However, the limited number of relevant articles included in the review suggests that the literature on this topic remains scarce (Hastreiter et al., 2013).

Benchmarking seeks to identify best practices and aims to match or exceed best–in-class performance. Best practices from fields such as SCM and BPM can offer opportunities for improvement in healthcare, for example (Aitken, Childerhouse, Deakins, & Towill, 2016; Callender & Grasman, 2010; Hung, 2006). However, the healthcare sector has not reaped the same benefits from adopting SCM practices as other industries. Despite many healthcare organisations having recognised the importance of adopting SCM practices (de Vries & Huijsman, 2011), continued lack of executive management support for SCM practices and failing to align incentives across the healthcare supply chain have led to poor supply chain performance in the healthcare industry (Mckone-Sweet et al., 2005).

Korpela and Tuominen define five critical success factors in logistics: reliability, flexibility, lead time, cost-effectiveness, and value-added. They apply the Analytic Hierarchy Process (AHP) method to determine logistics performance and enable the comparison of logistics performance across companies (Korpela & Tuominen, 1996). At a more strategic level, Díaz and colleagues benchmark supply chain and logistics practices of Spanish companies to best practices identified in the literature. The best practices identified and benchmarked include the following (Díaz, Claes, Solís, & Lorenzo, 2011):

- Top management understanding and support of SCM
- Strategic focus on cost-effectiveness
- Integration towards suppliers
- Strategic relations with suppliers
- High degree of trust
- Measuring logistics and supply chain performance indicators

Thus, differing views exist on what constitutes as best practices in SCM and logistics. However, several authors mention managers' understanding of and support of SCM and logistics initiatives as pivotal to the success of implementing these practices (Callender & Grasman, 2010; Díaz et al., 2011; Mckone-Sweet et al., 2005; Ralston, Grawe, & Daugherty, 2013). Lack of management commitment can lead to benchmarking being superseded by other management approaches such as BPR that may experience the necessary executive attention (Simpson, Kondouli, & Wai, 1999).

Few studies exist on best practices in healthcare logistics. Callender and Grasman recommend a set of best practices for material management in healthcare based on SCM practices. These best practices relate to education, inventory management, procurement and contracting, and information sharing and collaboration/cooperation. The recommendations include increased training and education on SCM practices, the use of computer software to manage inventories, automating ordering processes using electronic data interchange (EDI) or Internet-based solutions, sharing inventory-related information with vendors, and finally involving healthcare providers such as physicians in product selection. These best practices can help material managers provide services at a lower cost, whilst maintaining quality of care. Callender and Grasman furthermore identified a list of barriers to SCM practices: conflicting goals regarding inventory, constantly evolving technologies, physician preferences for certain products, lack of barcode standards for products, and finally limited information sharing (Callender & Grasman, 2010). In addition, investigating supply chain innovation as a SCM practice in healthcare, S. M. Lee, Lee, and Schniederjans (2011) found that supply chain innovation positively affects supplier cooperation, supply chain efficiency, and quality management practices, which in turn improve the organisational performance in hospitals.

A benchmarking study of the organisation of operating theatres by Longo and Masella considers both clinical and logistical processes. Logistics and support processes such as patient transport, cleaning of the operating theatre, management of medical aids, management of medical instruments, and sterilisation of components are included in the investigation. The AHP method is used to evaluate scenarios for different types of processes to identify best practices. The study identifies quality, income, and costs as performance drivers and conducts an AHP analysis that considers three underlying criteria to identify best practices: perceived quality, environmental quality, and value-added (Longo & Masella, 2002). Along the same lines, Hastreiter and colleagues propose a benchmarking approach for healthcare logistics services that measures productivity, quality, and costs. This approach is applied to six German hospitals to enable the comparison of logistics service performance (Hastreiter et al., 2013). Similarly, Jehle and colleagues perform a benchmarking study of patient transport logistics in six German hospitals measuring productivity, quality, and costs. They identify six factors affecting performance: (1) variability in transport demand, (2) number of transports, (3) number of acute and operating theatre transports, (4) number of lifts for people and beds, (5) number of floors, and (6) number of bed and patient transports (Jehle et al., 2015).

Benchmarking the supply of materials is another aspect of healthcare SCM that holds great potential for cost savings: first, by helping ensure that hospitals do not pay overprices for products and, second, by helping improve contracts with suppliers (Troolin, 2000). Böhme and colleagues provide a practice-focused benchmarking study on the reliability of medical healthcare supplies in hospitals. They identify failure of management to recognise the importance of supplies together with poor management systems in the supply chain as the reason for poor supply chain performance (Böhme, Williams, Childerhouse, Deakins, & Towill, 2016).

In addition to the forward flow of goods, a reverse flow exists for products such as pharmaceuticals. Xie and Breen benchmark the logistics systems of household waste pharmaceuticals against the reverse logistics of batteries and identify opportunities for improving reverse logistics of pharmaceutical products (Xie & Breen, 2014). Thus, the benchmarking study compares a reverse logistics process in healthcare to a reverse logistics process of another industry but with similar characteristics.

Other studies include that of Swinehart and Smith, who provide a method for using internal customer satisfaction data to measure internal healthcare supply chain performance (Swinehart & Smith, 2005). Lega, Marsilio, and Villa (2012) provide a framework for measuring supply chain performance in the public healthcare sector based on three dimensions: (1) set-up and operating costs, (2) financial benefits, and (3) organisational and process benefits. Finally, Villa et al. (2014) propose a framework for evaluating patient flow performance at three different levels: (1) hospital, (2) hospital pipelines, and (3) production units.

Some challenges relating to benchmarking healthcare logistics have been identified in the literature. First, examples from the UK show that benchmarking within healthcare has served more as a political instrument than as a vehicle for sharing best practice. Moreover, benchmarking led to hospitals taking a defensive stance trying to justify differences in performance rather than promoting continuous improvement (Northcott & Llewellyn, 2005). Second, identifying best practice and developing comparable benchmarks are particularly challenging in public and healthcare settings (Kouzmin et al., 1999; Magd & Curry, 2003; Northcott & Llewellyn, 2003; Wynn-Williams, 2005). Third, benchmarking supply chains in particular poses some methodological challenges due to the lack of information and political agendas (Böhme Williams, Childerhouse, Deakins, & Towill, 2013). Another issue with benchmarking supply chains is that most methodologies do not take into account that the importance of different performance measures and best practice aspects varies across firms (Simatupang & Sridharan, 2004). Finally, international benchmarking of hospitals is particularly challenging due to the added complexity of comparing different healthcare systems (van Lent et al., 2010).

This literature review shows that there is no consistent way of measuring supply chain and logistics performance in healthcare and thus agrees with the findings of Mckone-Sweet et al. (2005). The literature on benchmarking healthcare logistics processes is limited and challenges related to benchmarking healthcare logistics and supply chain processes have been identified. The current paper helps fill the literature gap and cope with the challenges identified for healthcare logistics and supply chain benchmarking.

Method

A case study was chosen as research design because it provides in-depth knowledge of a phenomenon (Yin, 1994). The case studies investigated in this paper are within the field of operations management, which is suitable for case studies and empirical studies (McCutcheon & Meredith, 1993; Voss, Tsikriktsis, & Frohlich, 2002). Moreover, a comparative case study was chosen to improve the validity of the findings.

The comparative case study consists of a multiple case study at five Danish hospitals and two case studies at a US hospital. The Danish hospitals were chosen because they are located within the same region and underlie the same governance structure and budget constraints. The US hospital was chosen because it ranks as a good hospital in the USA and provides a suitable basis for comparison. The case study hospitals are considered representative for hospitals in their respective countries and for hospitals in general.

The Danish multiple case study considered the bed logistics process at five Danish hospitals. The study conducted in Denmark was subsequently replicated for the bed logistics process and pharmaceutical distribution process at a US hospital. The bed logistics process in the USA was chosen to generalise the findings from Denmark to a US setting. The pharmaceutical distribution process in the USA was chosen to generalise the findings from the bed logistics process to other logistical processes.

Data were collected for the Danish study from February to August 2014 and for the US case studies from September 2015 to January 2016. The collected data were qualitative and quantitative in nature and were mainly gathered through interviews, observations, and a survey. Interview and observation guides were used to guide data collection in a three-stage process. First, direct process observations of each process step were carried out to map the processes. Second, a round of semi-structured interviews was carried out to learn more about the process steps, challenges, and implemented changes in order to identify the decision criteria (see Appendix 1). Third, a survey or structured interview was conducted to validate the identified decision criteria (see Appendix 2). At this stage, the respondents weighted each of the identified decision criteria according to importance for the design of their processes. For the Danish bed logistics case study, 12 observations, 16 semi-structured interviews, and 5 structured interviews were carried out. For the US bed logistics case study, data were collected through four observations, seven semi-structured interviews, and a survey sent to three respondents. For the US pharmaceutical distribution case, data were collected through three observations, six semi-structured interviews, and a survey sent to two respondents. The interviews lasted between $\frac{1}{2}$ and $1\frac{1}{2}$ hours and the observations lasted between $\frac{1}{2}$ and 1 hour.

Interview participants were selected based on their knowledge of the processes or their roles as decision-makers. In the Danish bed logistics study, 12 people were interviewed in one of the hospitals, including managers from the transport department, cleaning department, and maintenance department. Furthermore, staff involved in data management in addition to clinical staff, represented by a physician and a nurse, were interviewed. The number of interview participants was determined by the number of process steps, key decision-makers, and knowledge workers at each process step. This was to gain initial in-depth knowledge of the bed logistics process before gathering data at other hospitals. In the four other Danish hospitals, the manager of the bed logistics process was interviewed in both the semi-structured and structured interviews/surveys. In the USA, an interview person was selected at each step of the process to gain more in-depth knowledge of each process step. For the US bed logistics process, seven people were interviewed, including managers from Bed Management, Environmental Services, and Patient Transport Services. Three managers subsequently participated in a structured interview or survey, that is, one from each department. For the US pharmaceutical distribution process, five managers from the Inpatient Pharmacy, IT department, and the Continuous Improvement department were interviewed. A manager from the Inpatient Pharmacy and a manager from the Continuous Improvement department subsequently responded to a survey/participated in a structured interview.

The decision criteria (RQ1) developed in this study are based on the data gathered and analysed in the case studies, thus adopting an inductive approach for linking data to results. Decision criteria were identified by coding interview and observation data according to three analyses: (1) identifying challenges in the process, (2) identifying reasons behind implementing technologies, and (3) identifying reasons behind implementing process changes. Challenges reflect the improvement potential in a process to reach organisational goals (Locke & Latham, 2002; VandeWalle, Cron, & Slocum, 2001), and reasons behind implementing technologies and process changes reflect the decision criteria used in the past to improve processes. The identified challenges and reasons for implementing technologies and process changes were coded in the collected data. Patterns emerged within the codes and themes could thus be identified. Coding was an iterative process with patterns emerging that formed the decision criteria. The decision criteria that emerged from the codes were validated in the structured interviews/surveys, where the identified decision criteria were ranked by key decision-makers on a 0–10 scale of importance for designing logistics processes. The decision criteria were continuously adjusted during this validation process. The decision criteria identified and validated in the Danish case study were subsequently validated for the US case studies by conducting the same three analyses of data and validating findings in structured interviews/surveys.

To determine best practice benchmarks (RQ2), a range of the best key performance indicators (KPIs) in the relevant area were determined (Hanman, 1997), that is, performance measures that reflect the objectives of the organisation (Camp, 1995). The decision criteria ranked as most important for the Danish and US case studies were thus identified as those reflecting the objectives of the organisation and as relevant areas for measuring KPIs. Performance metrics were, therefore, suggested within these areas to determine best practice benchmarks.

Case study descriptions and initial comparison

The five Danish case study hospitals are public hospitals located in the capital region of Denmark. These hospitals vary in size from 250 to 700 beds. The US hospital is one of the top-ranking hospitals in the country. It is a non-profit organisation with several locations across the USA and outside of the USA. The main campus with approximately 1250 beds is the main focus of this study. An overview of the case study hospitals can be found in Table 1.

The Danish and US hospitals operate under very different circumstances. In contrast to the government-funded healthcare provided in Denmark, US healthcare is funded by insurance companies, government programmes, self-pay, donations, and grants. The financial structure also differs in the sense that US hospitals are partly reimbursed by government programmes based on hospital performance and patient satisfaction (Geiger, 2012; G. M. Lee et al., 2012; Rosenthal, 2007).

The bed logistics flow in the Danish hospitals involves the patient being placed in bed and undergoing treatment. When the patient is discharged, the bed is transported to a central cleaning area where the bed is cleaned and transported to a new patient. The beds are either cleaned manually or in washing machines. The clinical departments are responsible for bed assignment and patient discharges; the cleaning department cleans the rooms; the transportation department transports patients to treatment, clean beds to patients, and dirty beds to the central bed cleaning team. Throughout the process, limited process data are available apart from admission and discharge data.

Table 1. Overview of case study hospitals and their emergency department (ED) services.

Hospital	# beds	# discharge beds cleaned/day	24-hour ED in hospital?
DK hospital 1	700	235	Yes
DK hospital 2	600	250	Yes
DK hospital 3	500	175	Yes
DK hospital 4	400	110	No
DK hospital 5	250	120	No
US hospital	1250	200	Yes

The US bed logistics process is similar to the Danish bed logistics process, the only difference being that beds are cleaned in the wards. Furthermore, the information level in the US bed logistics process is higher than that for the Danish process. In addition to admission and discharge data, certain time stamps are registered for patient transport and cleaning through a teletracking system. A range of organisational units are involved in the bed logistics process: Bed Management assigns beds, Cleaning Services cleans rooms and beds, Transportation transports patients to the assigned rooms and to/from treatments, and the clinical departments admit and discharge patients.

The US pharmaceutical distribution process investigated in this paper focuses on the inpatient pharmacy. Pharmaceuticals are transported from the docking area to the inpatient pharmacy where they are checked with the orders. They are then transferred to the storage area where they are registered and stored in a picking carousel. Throughout the day, pharmaceuticals are picked from the carousel and delivered to clinical departments, where they are registered and stored in dispensing stations before being administered to the patients. The dispensing stations are refilled daily from the central inventory at a pre-scheduled time, whereas patient-specific pharmaceuticals are sent to the departments separately throughout the day. Pharmaceuticals are either transported manually or through pneumatic tubes. Between each handover in the process, pharmaceuticals are scanned using barcodes in order to enable item tracking and to ensure that correct items are handed over. At any point in time, the location of any pharmaceutical is known from the point of delivery in the pharmacy until it is administered to the patient. Most of the process is handled within one organisation, namely the Inpatient Pharmacy.

Comparing the bed logistics process to the pharmaceutical distribution process, the bed logistics process is characterised by disjunctive process steps that involve staff from several different departments who possess very different skill sets. Furthermore, most of the process steps are performed manually. By contrast, the pharmaceutical distribution process is handled by fewer departments and is a more automated process. Process automation provides data to enable performance measurement, analytics, and process improvement. Another significant difference between the bed logistics and pharmaceutical distribution processes is found in the characteristics of the items and flows. The pharmaceutical distribution process concerns the flow of small-sized items that enter the system from an external source, that is, the pharmaceutical manufacturers and wholesalers, and exits either at the point of consumption, when returned to the vendors, or when being disposed of. The bed flow, on the other hand, is a closed-loop flow of large items, that is, beds, which enter the system once, are reused, and finally exit the system when replacement is needed. The bed flow follows the patient flow to some extent and is used as a vehicle for transport, whereas pharmaceuticals are part of the patient treatment and encounter the patient at the point of consumption. Finally, the pharmaceutical distribution process is characterised by a higher degree of control due to strict legislation.

Results

Identifying and validating decision criteria

Decision criteria were identified by coding interview and observational data according to (1) challenges identified in the processes, (2) reasons behind implementing technologies, and (3) reasons behind implementing process changes. Examples of the links between data and decision criteria are provided for each of the three analyses in the following.

(1) *Challenges.* A main challenge in the pharmaceutical distribution process was how to use available information to make critical decisions faster and to optimise the use of technologies. For example, data were used to ensure the right inventory mix so that enough on-demand drugs were available, whilst at the same time limiting storage space. These challenges relate to the derived decision criterion *information management*.
(2) *Technologies.* Automated guided vehicles (AGVs) were implemented to transport pharmaceuticals from the docking area to the pharmacy. The AGVs were also used for transporting linen as well as other items around the hospital. The AGVs were implemented because of their fast response and delivery time in addition to prevention of employee injuries relating to manual transports. Derived decision criteria based on these arguments are *lead time*, *degree of automation*, *employee work conditions*, and *impact on related processes*.
(3) *Process changes.* A rigid seven-step cleaning process had been implemented in the US bed logistics process. This seven-step process was implemented to limit variance in the process and ensure a consistent result that lives up to cleaning requirements. Decision criteria derived from this analysis are *consistency*, *risk of mistakes*, *output quality*, and *competence match*.

To further exemplify the logic used to link data and derived decision criteria, a full overview of the link between data and decision criteria is provided for the analysis of technologies in the US pharmaceutical distribution process in Table 2. To economise on space, a full overview of the link between data and decision criteria is provided only for this analysis. However, the logic extends to all three cases and analyses. The example was chosen because it provides the most extensive illustration.

The described approach for identifying decision criteria was performed for all three case studies. Seventeen decision criteria were identified in the Danish and US case studies. Each of these decision criteria was weighted by Danish and US respondents according to importance regarding process design. Table 3 shows the average weights assigned by the Danish and US hospitals for the 17 decision criteria. The table is sorted in descending order according to the average weights for *all* respondents. The standard deviation (SD) for all respondents is lowest for the highest ranking decision criteria and seems to increase as the average importance of decision criteria decreases. This trend suggests that there is more consensus across respondents for the highest ranking decision criteria and less consensus for the lowest ranking criteria. Furthermore, there seems to be more agreement amongst respondents from the same country than amongst respondents from the same process type.

Identifying the most important decision criteria to enable benchmarking

Measuring performance aspects that are considered important for all processes enables benchmarking. It would be biased to compare performance metrics that are of high importance in one case study and low for another, as low performance could then be attributed to low importance. Table 3 shows the identified decision criteria in descending order according to importance for improving healthcare logistics processes. The five most important decision criteria based on Table 3 are as follows:

- Output quality
- Consistency

Table 2. Decision criteria derived from identified technologies in the US pharmaceutical distribution process.

Technology	Reasons for implementation and benefits	Derived decision criteria
AGVs	Transport pharmaceuticals to the pharmacy. Response time is fast and solution financially viable (also used for other transports). Saves injuries as carts are heavy.	Lead time Degree of automation Employee work conditions
EPIC	EPIC stores electronic medical and pharmaceutical records. The CPOEs (computerised physician order entries) and prescriptions are entered into EPIC.	Degree of automation Value-added time Information management
Pneumatic tubes	Pneumatic tubes are used for small pharmaceutical transports in cases of emergency. Transport time is 10–20 minutes.	Degree of automation Lead time
Picking carousels	Automated carousels are used for picking pharmaceuticals. The carouse indicates which drawer in to pick from, and a technician then picks the drugs.	Degree of automation Future proofing
Medication dispensing stations	Ensures availability of pharmaceuticals close to the patient and involves safety mechanisms for the patient.	Security of supply
MRP system	An MRP system is used that enables inventory management, purchasing, and finance.	Degree of automation Information management
EDI	Enables automatic reordering of pharmaceuticals.	Degree of automation Value-added time Information management
Med boards	Visual boards that together with barcodes enable tracking of pharmaceuticals – it is possible to see where the meds are at any particular moment in time.	Traceability Information management
Barcodes	Barcodes are used for tracking pharmaceuticals and for bedside verification. The patient's wristband and the pharmaceutical are scanned for verification.	Traceability Information management
RFID	Code boxes are tracked and through RFID technology.	Traceability

Table 3. Decision criteria weighted by the five Danish hospitals and the US hospital.

Existing decision criteria	Weights for DK bed logistics case	Weights for US bed logistics case	Weights for US pharmaceutical distribution case	Weights for all respondents	
				10	
# respondents	5 *Average*	3 *Average*	2 *Average*	*Average*	*SD*
Output quality	9.8	9.0	9.5	9.4	1.0
Consistency	9.4	9.3	9.5	9.4	1.0
Employee engagement	9.4	9.7	9.0	9.4	1.1
Risk of mistakes	10.0	8.0	10.0	9.4	1.6
Security of supply	9.4	8.7	10.0	9.3	1.5
Information management	8.4	9.3	10.0	9.0	1.5
Employee work conditions	9.6	8.7	8.0	9.0	1.7
Lead time	8.4	8.7	8.5	8.5	2.0
Traceability	7.4	9.3	10.0	8.5	2.5
Value-added time	8.5	8.3	8.0	8.4	2.0
Impact on related processes	8.3	9.0	5.0	7.9	2.1
Unnecessary process	6.3	8.3	8.0	7.3	2.3
Competence shift	5.6	9.0	8.5	7.2	3.2
Future proofing	8.0	6.3	5.5	7.0	2.7
Competence match	5.6	8.3	8.0	6.9	3.3
Degree of automation	7.8	5.7	5.5	6.7	2.7
Environmental considerations	9.0	5.3	1.5	6.4	3.5

- Employee engagement
- Risk of mistakes
- Security of supply

Each of these five decision criteria are now discussed in turn and compared for the three cases. Furthermore, suggestions for how these decision criteria could be operationalised as performance metrics to enable benchmarking are proposed.

Risk of mistakes could be measured based on the error rate occurring in a process. In the US pharmacy, the error rate for picking pharmaceuticals is currently measured. In the US bed logistics process, patient satisfaction is measured for all patients and cleanliness is checked daily by supervisors for a random sample of rooms. Similarly, a random sample of rooms is checked for the Danish bed logistics process. However, it is time consuming to check the cleanliness of a room and applying a tool such as Six Sigma could, therefore, prove difficult. Six Sigma reflects the likelihood of an error occurring by measuring variability in terms of SD. However, the low defect rate for a Six Sigma process of 3.4 defects per million may not be necessary for logistics processes in healthcare. A higher SD may be allowed, for example, three sigma, leading to less *consistency* in the process. The allowed level of variability may, therefore, vary depending on the process and how easy it is to measure variability. Lastly, *output quality* refers to how good a product or a service is. This is the notion of quality as 'conformance to requirements' (Crosby, 1979; Lewis & Hartley, 2001); *output quality* being the requirement and level of tolerated failure being the allowed variance. Some of the Danish hospitals use washing machines to wash the beds, which leads to cleaner beds than when they are washed by hand. Employees washing the beds by hand are not necessarily making a mistake, but the conditions are not there to achieve the same level of cleanliness. However, mistakes are more likely to occur in a manual process. A system may, therefore, only allow for certain levels of output quality. Another output quality measure could be the level of service provided. For example, service level agreements on lead time were established for patient transports and discharge room cleaning in the US hospital.

Employee engagement. Motivation of employees and ensuring employee engagement were identified as challenges in all case studies. However, 'how do you motivate someone that isn't really motivated?' as a manager in bed logistics pointed out. Employee turnover and absenteeism were high in all case studies. It is therefore important to measure employee turnover and absenteeism, for example, the average number of sick days per employee or the absence rate. Furthermore, to ensure employee retention, measuring employee satisfaction and finding out the reasons behind employee satisfaction levels are vital. This could be done through periodical surveys, talking to the employees, or having the employees indicate job satisfaction levels daily through a red/green/yellow 'traffic light' or 'smiley' system, which are frequently used reporting structures (Neely, Adams, & Kennerley, 2002). Another measure of employee engagement or employee involvement as suggested by Neely et al. (2002) is the percentage of employees providing a number of implementable improvement suggestions.

Security of supply is particularly important for pharmaceuticals due to the impact on patient treatment. A way to monitor security of supply would be to measure the rate of fulfilled orders by suppliers or the rate of fulfilled patient orders. The hospital may be able to accommodate hospital demand for a while without replenishing stock, but for how long would depend on the reorder point for each product. For the bed logistics process, supply refers to either (1) cleaning supplies, (2) supply of clean beds, or (3) supply of transport and cleaning staff. First, shortages in cleaning supplies do not occur as the items do not have an expiration date and are easy to restock. Second, shortages in the supply of clean beds translate into waiting time for the patients, which could be measured as time-to-bed assignment for patients. Finally, shortages in cleaning staff have occurred for the US hospital, particularly when the area experienced a snow storm and many employees could not get to work. Despite the lack in resources, the hospital still managed to clean all rooms to a fair standard. Therefore, security of supply does not apply to the supply of human resources and cleaning supplies in the bed logistics process.

Discussion

There seems to be consensus across respondents on high-ranking decision criteria and less consensus as the average weight of importance decreases. The results suggest that disagreement on the importance of the lower ranking decision criteria depends on the specific process type and national context. Hence, international benchmarks may differ slightly compared to benchmarks with peers restricted to a national level. Conversely, the agreement on the higher ranking decision criteria suggests that these decision criteria are of high importance regardless of the context and process type. Overall, the identified decision criteria, except for *environmental considerations*, were found to be valid in both a Danish and a US context and for bed logistics processes as well as other hospital logistics processes such as pharmaceutical distribution. Furthermore, the decision criteria address both efficiency and effectiveness aspects of performance; for example, *downtime and maintenance* and eliminating *unnecessary processes* address efficiency, whereas *output quality* and *employee engagement* address effectiveness. Thus, RQ1 is answered through the validation of decision criteria for the Danish and US case studies.

Quality measures, *employee engagement*, and *security of supply* were identified as the most important aspects of healthcare logistics processes. In addressing RQ2, performance indicators were suggested based on these decision criteria. Existing benchmarking studies on healthcare logistics have focused on customer satisfaction (Swinehart & Smith, 2005), organisational benefits, process benefits including quality service levels, financial benefits, and set-up and operating costs (Lega et al., 2012). The quality aspects considered by Lega et al. (2012) are delivery performance, time to deliver, flexibility, distribution of workloads, and accuracy and timeliness of information. Most of these aspects relate to lead time or time savings, which in this study correspond to the suggested *output quality* measures on lead times for transport and discharge cleaning. The need for methods that incorporate quality in benchmarking in healthcare is, therefore, addressed (Hussey et al., 2009). Delivery performance as mentioned by Lega et al. relates to the identified decision criterion *security of supply*. A benchmarking study by Böhme et al. (2016) investigates how to improve the reliability of value streams in hospitals, which can be similarly translated into the decision criterion *security of supply*. Thus, two of the most important aspects of healthcare logistics identified in this study are consistent with the existing literature. Moreover, this paper recognises the importance of reliability in healthcare value streams and contributes to the literature on how to improve reliability of value streams in hospitals.

The last benchmark and decision criterion identified in this study is *employee engagement*. Making sure that the right employees with the right skills are hired is one of the main challenges identified in the pharmaceutical supply chain and is vital for further supply chain improvements (Privett & Gonsalvez, 2014). Human factors are often overlooked in the operations management literature, but failure to recognise the importance of human factors in operations design can impede operational performance (Boudreau, Hopp, McClain, & Thomas, 2003; Grosse, Glock, Jaber, & Neumann, 2015). Typical human resource management (HRM) studies investigate the effect of certain HRM practices on individual behaviour such as turnover, absenteeism, job satisfaction, and performance, for example (Boudreau et al., 2003; Huselid, 1995; Rodwell, Lam, & Fastenau, 2000). Similarly, employee satisfaction, turnover, and absenteeism metrics were suggested as important metrics in this study to capture *employee engagement*. The challenge of high absenteeism and turnover in logistics settings has been reported in logistics literature, for example (Grosse et al., 2015; Min, 2004, 2007), and is validated in this study for a healthcare logistics setting. Some benchmarking literature in healthcare recognises the importance of human factors and HRM (Sargiacomo, 2002; Xiong et al., 2015). However, the literature on healthcare logistics fails to recognise the importance of the human factor and HRM. The current paper identifies human factors as important in the delivery of high-quality logistics services in hospitals and recommends that human factors are considered in benchmarking efforts.

Quality seems to be a recurring aspect identified in this study and the benchmarking literature within healthcare logistics (Hastreiter et al., 2013; S. M. Lee et al., 2011; Longo & Masella, 2002), service logistics (Altuntaş Vural & Tuna, 2016; Blumberg, 1994; Kilibarda, Zečević, & Vidović, 2012; Thai, 2013), and manufacturing logistics (Bagchi, 1996; Daugherty, Dröge, & Germain, 1994; Van Landeghem & Persoons, 2001). The time aspect is also a recurring theme, which in turn relates to the *quality* aspect in healthcare logistics. Finally, Van Landeghem and Persoons (2001) mention flexibility and reaction time, which relate to *security of supply* and other identified decision criteria.

Some challenges related to benchmarking supply chains in healthcare logistics have been addressed. Quantifying the importance of each decision criterion addresses the issue of differences in the importance of performance measures and best practice across firms (Simatupang & Sridharan, 2004), borders (van Lent et al., 2010), and context (Sousa & Voss, 2001, 2008). According to Sousa and Voss (2001, 2008), the contextual conditions of an organisation determine the use and fit of operations management practices in an organisation. This paper suggests that the suitability of a process design depends on the preference regarding certain decision criteria and that priorities may differ according to process type and organisational/national context. However, there seems to be agreement on the most important decision criteria.

Conclusions and limitations

This paper contributes to the limited performance measurement and benchmarking literature identified in the field of healthcare logistics. First, a method for benchmarking healthcare logistics processes is proposed. A set of 17 decision criteria has been identified that should be considered when designing logistics processes in a healthcare setting. Second, *quality measures*, *security of supply*, and *employee engagement* were found to be the most important decision criteria across process types, organisational borders, and country borders, and therefore most suitable as generalisable benchmarking metrics. Thus, the need for quality-focused benchmarking in healthcare is addressed. Moreover, the study stresses the importance of human factors and HRM in the delivery of high-quality logistics services in hospitals, which the extant literature fails to recognise. Furthermore, addressing *security of supply* helps achieve supply chain reliability in a healthcare setting. Fourth, the proposed method copes with challenges related to healthcare supply chain benchmarking, particularly differences in the importance of performance aspects and benchmarking across borders. Fifth, the country setting seems to determine the importance of decision criteria rather than process type.

The findings of this study are relevant for decision-makers within healthcare logistics to understand (1) which decision criteria are important for designing logistics processes in a healthcare setting and (2) how this understanding can be used for benchmarking. However, more literature is needed on benchmarking and best practices in healthcare logistics. For example, what should be benchmarked and what is the best process design under which circumstances? Moreover, the financial aspect found in the benchmarking literature has deliberately been excluded from the current study. The authors recognise the importance of this aspect in the decision process and a financial analysis is seen as complementary to this study. Another limitation of this study is that there is no comparison to a Danish pharmaceutical distribution process. Furthermore, the study is limited to two types of processes. Future studies should be conducted in other countries and for other logistics processes in hospitals or even other industries. A survey on a larger population of hospitals would enable statistical analyses to further validate the findings of this study. In addition, specific process improvement philosophies or strategies such as lean or agility could be assessed using the identified decision criteria. Such research would fall within the research stream of operations management practice contingency research, for example (Sousa & Voss, 2001, 2008).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1

Appendix 1 provides the interview guide used for the first round of interviews carried out for each investigated process.

Preparation

Background: The project focuses on how to improve logistical processes in hospitals, particularly through the use of technologies and changes to the process steps. The bed logistics process and pharmaceutical distribution process are in focus.

Purpose: To learn about the process, the challenges in the process, the reasons for implementing improvement initiatives (process changes, implementation of technologies, etc.), and the effects of these changes (on logistics, technology, structure, and procedure).

Interview questions

Background questions

(1) What is your role?
(2) What are the responsibilities of your department?
  (a) Which tasks do you undertake?
  (b) Do you have different units in your department?
  (c) Do you have an organisational chart available for me to see?
  (d) How many people work there?
(3) Describe the process steps of the process.

The use of technologies and the implementation of process changes

(4) Which technologies/process changes have you implemented?
(5) When did you start using these technologies/process changes?
(6) What do you use the technologies for?
(7) Why did you decide to use these technologies/process changes?
  (a) What were the main drivers for deciding to use that technology rather than other technologies?
  (b) Do the reasons vary depending on the process?
  (c) Which challenges did you hope to overcome by implementing technologies?
  (d) Which decision parameters did you use?
(8) Validate decision indicators in framework – were others used? Where some not used?
(9) Did you test other types of technologies in those processes before implementing?
(10) What were the main challenges in the process before you implemented the technologies/made process changes?
(11) What are the main challenges for the processes now?
(12) What challenges have you had with the technologies?
(13) Have any of the technologies that you have implemented/tried to implement failed?
  (a) If so, why?
(14) What have been the main benefits of implementing technologies?
(15) What good or bad effects have you experienced after implementing the technologies or other improvement initiatives?
(16) How do employees interact with the technologies?
(17) When would you choose to use technologies over other types of improvement?
(18) When would you rather use human resources?
(19) How have the employees received the use of technologies?

Data and performance measurement

(20) Do you use any KPIs to measure process performance?
  (a) If yes, which KPIs do you use?
  (b) Why have you chosen those KPIs?
  (c) How do you capture data to measure the KPIs? (RFID, barcodes?)
  (d) Have your KPIs improved since implementing technologies/change initiatives?
    (i) Are the improvements also due to other improvement initiatives?
    (ii) How much did the KPIs improve?
(21) Do you consider the process a good process?
  (a) Why/why not?
(22) Is the process best practice?
  (a) Why/why not?
  (b) What characterises the process?

Future prospects

(23) Do you see the implemented technologies as something you would invest in in the future or are there other technologies that are more interesting?
(24) If you could have three wishes granted for the processes, what would that be?
(25) Any changes in pipeline?

Documents and further research

(26) Do you have any process maps that I can have a look at?
(27) Do you have any presentations/proposals for implementing AGVs that I may see?
(28) Do you have any executive reports on performance that I may see?
(29) Can I use my findings for publication?
(30) Further interviews and observations possible?
  (a) Process observations possible?
  (b) Employee shadowing possible?
  (c) Follow-up interviews possible?
(31) Thank you for your time – anything to add?

Appendix 2

Table A1 depicts the survey sent out to decision-makers in the bed logistics and pharmaceutical logistics case studies. The respondents were asked to weight the decision criteria on a 0–10 scale according to their importance when improving healthcare logistics processes.

Table A1. Validation of identified decision criteria

Decision criterion	Description	Weight (0–10)
Lead time	Time from order to delivery	
Value-added time	% of lead time adding value	
Security of supply	Ensuring the right amount at the right time	
Traceability	Enabling track and trace	
Degree of automation	How automated is the process?	
Information management	The ability to collect, analyse, and communicate data	
Environmental considerations	Sustainable use of energy, chemicals, renewable materials, etc.	
Risk of mistakes	Likelihood of mistakes occurring	
Consistency	Standardisation of the process and process output	
Future proofing	Will the solution sustain in five years? Is it flexible?	
Impact on related processes	Negative and positive impact on other processes. For example, other use for technology or increased workload for others	
Output quality	Quality of product/service delivered	
Competence shift (handovers)	Number of handovers in the process	
Competence match	Do the competencies of the employees match the needs of the new process or is training needed?	
Unnecessary process	Can the process be avoided?	
Employee engagement	Is the employee motivated to perform the job? Is an incentive provided?	
Employee work conditions	Employee safety, work load, strenuous work, ergonomics, physical and psychological work environment	

PAPER 5

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Relations between decision indicators for implementing technology in healthcare logistics – a bed logistics case study

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Abstract
The cost of healthcare is rising and reforms have been introduced across Europe to address the cost issue in healthcare. There is potential to improve logistical processes within healthcare to save costs and at the same time provide services that support high quality patient care. Re-designing processes and implementing technology can improve the efficiency of processes and reduce costs. A relations diagram has been developed that identifies the effects between the constructs *Logistics*, *Technology*, *Procedure* and *Structure*. Knowledge about how these constructs affect each other is important when deciding how to re-design processes and which technologies to implement.

Keywords: Healthcare logistics, technology assessment, process management

Introduction
The cost of providing healthcare is rising and the pressure for providing high quality services at lower costs in healthcare is increasing (OECD, 2013). Reforms have been introduced across Europe to address the healthcare cost issue. Currently, hospitals are being built across Denmark to create highly specialized hospitals in order to improve healthcare quality and lower costs (Andersen and Jensen, 2010).

Logistical processes are essential for a hospital to function and in providing services for the patients. According to Poulin (Poulin, 2003), over 30% of hospital costs are related to logistical activities and almost half of the logistical costs could be eliminated through the use of best practice. Improving the efficiency and effectiveness of healthcare processes not only economizes on resources but also improves the quality of services. Process improvements can be achieved through the use of different tools such as Business Process Reengineering (Hammer, 1990) or Lean (Womack et al., 1991) by eliminating process steps that do not create value for the patient. One way of improving process efficiency is to take advantage of technological solutions (Hammer, 1990; Jimenez et al., 2012; Voss, 1988).

Bed logistics is vital for the patient flow. This paper builds on a multiple case study investigating the bed logistics process at five Danish hospitals. Based on this multiple case study, a framework was developed to assess which technology to implement in a logistical healthcare process. The case studies identified 19 decision indicators for assessing a technology. These indicators each relate to one of the following constructs: *Logistics*, *Technology*, *Procedure* and *Structure (LTPS)*. *Logistics* refers to managing the flow of goods in a process, *Technology* refers to machinery, electronic devices and information systems, *Procedure* refers to the logistical process steps, e.g. as described in standard operating procedures, and *Structure* refers to the organizational structure. It is important for management within logistics to understand how these constructs interrelate when implementing technology and improving processes. Research exists on the individual construct relations (e.g. *Technology* and *Structure* (Leonard-barton, 1988; Mital and Pennathur, 2004; Neumann and Dul, 2010)) and to some extent on more than two constructs (Hammer and Champy, 1993; Jørgensen, 2013; Leavitt, 2013). However, there is a need to understand all the indicators' interrelations in a healthcare logistics context. This paper aims to develop a relations diagram that elucidates how the four *LTPS* constructs relate to each other in a healthcare logistics setting.

Methodology

In this section, the research objectives, research design, data collection, analysis of data, and data validation are described for the study.

Objectives

This paper investigates the following research question through a multiple case study conducted at five Danish hospitals:

- *How do the constructs Logistics, Technology, Procedure and Structure relate to each other in terms of effects in a healthcare logistics setting?*

The research question is answered through the following sub questions (SQs):

1) What does case study data suggest about the relationship between identified indicators relating to *Logistics*, *Technology*, *Procedure* and *Structure*?
2) What would the effects be on *Logistics*, *Technology*, *Procedure* and *Structure* if the technologies suggested and discussed in the case studies were implemented?
3) What does literature suggest about the relationships between identified indicators relating to *Logistics*, *Technology*, *Procedure* and *Structure*?

The aim is to develop a relations diagram that provides an overview of the effects of re-designing logistical healthcare processes by implementing technologies. The research question is answered by performing different analyses to identify relations between indicators. Relations between the LTPS constructs are elucidated through the identification of relations between the underlying indicators. These indicators were identified as the decision indicators that are important when deciding on how to re-design logistical healthcare processes by implementing technologies. By only focusing on relations between the identified indicators, the scope is narrowed down to relations between those indicators that have been identified as the most important for re-designing processes by implementing technologies. Therefore, only the relations that are of consequence to the decision process are considered in this study.

The first sub question is answered by identifying relations between indicators through case study data. To answer the second sub question, the effects on indicators by implementing technologies in the bed logistics process are analyzed. Lastly, effects between indicators have been identified in literature.

Case study as research design

Case study research can enrich the theoretical field of operations management (McCutcheon and Meredith, 1993; Voss et al., 2002). This study is based on qualitative research and is a multiple case study within the theoretical field of operations management. The unit of analysis is the bed logistics process and data was gathered at five Danish public hospitals. The overall research question is a “how” question and is of an explanatory nature, which makes the research suitable for a case study (Yin, 1994).

The five hospitals were selected because they are located within the same hospital district, which means they are subject to the same requirements and financial constraints. Hospitals of different sizes were chosen to include two small hospitals (250 and 300 beds capacity), a medium sized hospital (500 beds capacity) and two large hospitals (600 and 700 beds capacity). Furthermore, the hospitals had different levels of technology maturity, i.e. some had implemented technologies that others had not.

Data collection

Data was collected over a seven month period from February to August 2014 at five Danish hospitals. One hospital served as a primary collaborating hospital. Qualitative data was collected mainly through interviews and observations and was done in three stages: 1) a preliminary stage, 2) a round of semi-structured interviews and 3) a round of structured interviews validating the results. In the preliminary data collection stage, interviews and observations were carried out at the primary collaborating hospital. Here, 12 open interviews were conducted with managers of the bed cleaning departments. Furthermore, observations of processes were made on eight occasions while at the same time interviewing employees carrying out the processes. The observations are best described as direct observations but with some interaction with the people involved in the process. A round of semi-structured interviews and observations were then carried out with managers at each of the other four hospitals. These managers were responsible for the cleaning of the beds. This was followed by a round of structured interviews with the managers from each of the five hospitals to validate their response.

The purpose of data collection in the preliminary stage was to learn about the process, the challenges in the process and any improvement potential. Based on these interviews and observations at the primary hospital, an interview guide was developed to guide the round of semi-structured interviews and observations at each of the other four hospitals. The purpose of the semi-structured interviews and observations was to determine the decision constructs to evaluate technologies to implement in a logistical process. Furthermore, the preliminary stage as well as the round of semi-structured interviews provided in-depth knowledge about the indicators that were used to identify relations between them. Data collected from the semi-structured interviews and observations at each hospital was then consolidated to make a full list of decision criteria. The full list was presented to the managers from each of the five hospitals for respondent validation.

Analysis

Figure 1 depicts a framework developed during the study. The framework is a decision tool for re-designing logistical healthcare processes by implementing technology. The framework consists of the four LTPS constructs and 19 underlying decision indicators that reflect overall process performance. The indicators have been divided into efficiency and effectiveness as performance measures should reflect both. Efficiency refers to how well resources are utilized and effectiveness refers to the extent to which goals are accomplished (Mentzer and Konrad, 1991).

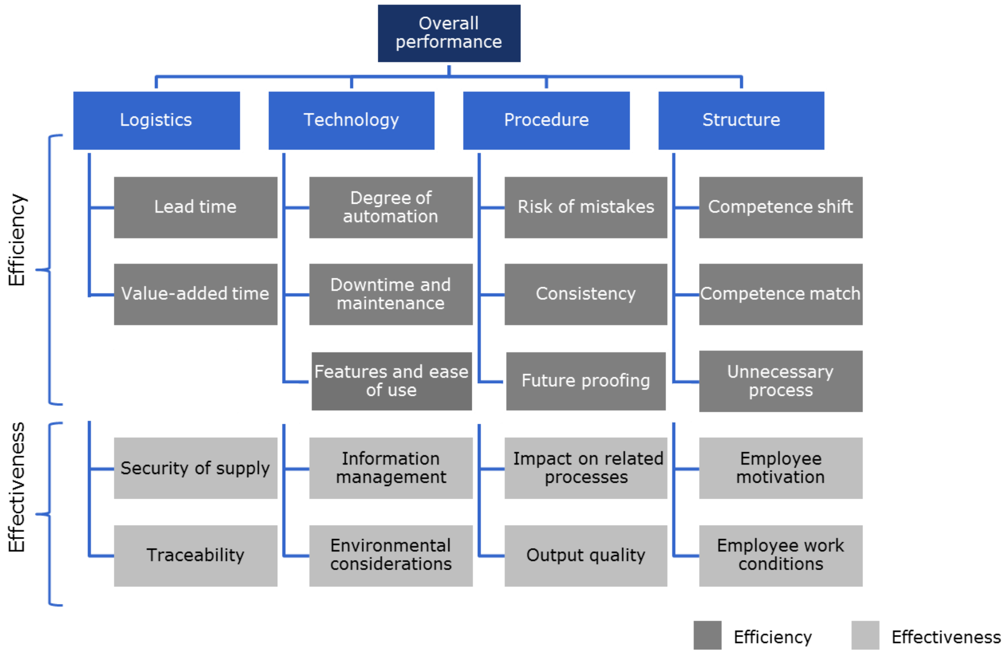

Figure 1 - Decision indicators identified for technology implementation in healthcare logistics

The three SQs will be answered for each relational pair between the four constructs (i.e. six pairs of relations). Qualitative data gathered from the five hospitals was coded in the qualitative data analysis tool NVivo. Data was coded according to themes that emerged from case study data and divided into *Logistics*, *Technology*, *Procedure* and *Structure* as in a similar study by Jørgensen (Jørgensen, 2013). Based on the codes, the framework with the four constructs and 19 underlying indicators was developed. Data gathered in the case studies provides detailed descriptions and knowledge about each of the indicators and the relations between them. The ability of the NVivo software to identify relations between codes was used in the analysis of the indicators to identify relations between the LTPS constructs. This analysis answered SQ1.

To answer SQ2, the technologies discussed in the five case studies were analyzed in turn to assess the effect on each of the *LTPS* indicators if implemented. These effects could be anticipated as a consequence of implementing the different technologies. An example of this is the effect on lead time of implementing an automated guided vehicle. Some effects, however, would not be evident until after implementation and would not be captured in the analysis. The effects of technologies that had already been implemented were captured in SQ1. Furthermore, some relations between indicators can be found in literature, which answers SQ3.

Relations between indicators have been identified in the following ways: a) in the case studies (SQ1 and 2), b) in the case studies and supported by literature (SQ 1, 2 and 3) or c) in literature as a relation between two indicators (SQ 3). For some of the relations suggested in the case studies, there was not enough data to support the claim. In c), these relations were further investigated and supported by findings in literature. This generalization from specific observations makes the reasoning inductive.

Validity and reliability

Construct validity is mainly related to the data gathering phase and refers to the extent to which a study investigates what it claims to investigate (Denzin and Lincoln, 1994). Construct validity was ensured through triangulation by gathering and analyzing data from different sources and by adopting different strategies for gathering data. Different sources of information were accessed; managers and employees at the primary hospital and managers at the four other hospitals. The different strategies adopted for collecting data were interviews and observations. Furthermore, validation was ensured through respondent validation (Bryman, 2012) where findings were reviewed by key informants (Yin, 1994). Furthermore, a round of interviews with managers from each hospital was conducted and recommendations were presented and discussed with management at the primary hospital.

Internal validity refers to the causal relationship between variables and results. Internal validity is only appropriate for explanatory or causal studies and is mainly relevant to the data analysis phase (Yin, 1994). This paper is an explanatory case study and the internal validity is ensured through different measures. Alternative explanations are ruled out by comparing results to a type of baseline. For some of the hospitals, certain technologies had already been implemented. Effects could therefore be compared to hospitals where technologies had not been implemented or to how it had been before implementation. Some of these effects were supported by literature. Some effects were identified in literature where relations between certain identified indicators seemed plausible but had not been sufficiently supported in the case study.

Finally, reliability and external validity are considered. External validity establishes within which domain findings can be generalized (Yin, 1994). External validity in this study is limited to a healthcare logistical context and needs to be tested in other countries and logistical settings. Reliability refers to the extent to which the same results and conclusions would be reached if the study were repeated. Reliability was ensured through colleague review and triangulation (Miles et al., 2014).

Identified relations between indicators and constructs

Figure 1 illustrates the decision indicators identified for implementing technology in healthcare logistics. Each decision indicator was identified in the bed logistics case study conducted at five Danish public hospitals. Data gathered from case study interviews and observations provides details about the indicators and insights about the relationships between them. The identified relations between decision indicators and constructs are presented in this section.

To identify relations between the LTPS constructs, each of the six pairs of constructs were compared by comparing the underlying indicators. E.g. the indicators belonging to *Technology* were compared to those belonging to *Procedure* in order to identify any effects between them. One of the identified effects was the positive effect of *degree of automation* on *consistency* and consequently of *Technology* on *Procedure*. This was supported by a case example and literature. Table 1 provides an overview of the 32 identified relations and supporting evidence. Details of supporting data and literature can be found in a separate document. The indicators *future proofing* and *environmental considerations* were found to have no relations to any other indicators.

The identified relations were based on case study data, findings in literature or both. The effects have been characterized as negative, positive or with a possibility of each. Whether the effect is positive or negative reflects the effect on efficiency or effectiveness. The effects listed in Table 1 are summarized in Table 2 to provide an overview of which constructs affect other constructs the most and which constructs are affected the most.

Table 1 – Identified effects between constructs are negative, positive or possibly both

Effect of	Effect on	Ef-fect	Case ex.	Literature
Technology (T) vs. Procedure (P)				
Features and ease of use (T)	Output quality (P)	+	Yes	Automation and quality mgmt. (QM)
Features and ease of use (T)	Effect on related processes (P)	+/-	Yes	Lean
Degree of automation (T)	Risk of mistakes (P)	+	No	BPR and QM
Degree of automation (T)	Consistency (P)	+	Yes	BPR and QM
Technology (T) vs. Structure (S)				
Degree of automation (T)	Working conditions (S)	+	Yes	Ergonomics
Degree of automation (T)	Unnecessary processes (S)	+	Yes	Ergonomics
Features and ease of use (T)	Employee motivation (S)	+/-	Yes	Technology Acceptance Model
Features and ease of use (T)	Competence match (S)	+/-	Yes	Humans and automation, BPR
Degree of automation (T)	Competence shifts (S)	+	Yes	Automation
Information management (T)	Employee motivation (S)	+/-	No	Performance mgmt.
Logistics (L) vs. Technology (T)				
Traceability (L)	Enables information management (T)	+	Yes	RFID technology and performance mgmt.
Features and ease of use (T)	Lead time (L)	+/-	Yes	Automation
Downtime & maintenance (T)	Value-added time (L)	-	Yes	Lean
Downtime & maintenance (T)	Security of supply (L)	-	Yes	
Procedure (P) vs. Logistics (L)				
Risk of mistakes (P)	Value-added time (L)	-	Yes	Lean
Improved output quality (P)	Value-added time (L)	+	Yes	
Improved output quality (P)	Lead time (L)	-	Yes	
Risk of mistakes (P)	Security of supply (L)	-	Yes	Lean, risk mgmt.
Structure (S) vs. Logistics (L)				
Unnecessary processes (S)	Value-added time (L)	-	Yes	Lean, BPR
Unnecessary processes (S)	Lead time (L)	-	Yes	Lean, BPR
Competence shifts (S)	Value-added time (L)	-	Yes	Lean, BPR
Competence shifts (S)	Lead time (L)	-	Yes	Lean, BPR
Competence match (S)	Value-added time (L)	+	Yes	Learning
Competence match (S)	Lead time (L)	+	Yes	Learning
Traceability (L)	Competence shifts (S)	+	Yes	RFID technology
Structure (S) vs. Procedure (P)				
Competence shifts (S)	Risk of mistakes (P)	-	Yes	BPR
Competence shifts (S)	Consistency (P)	+/-	Yes	BPR
Competence match (S)	Consistency (P)	+	Yes	Learning
Employee motivation (S)	Output quality (P)	+	Yes	HRM and TQM
Competence match (S)	Output quality (P)	+	Yes	Learning and QM
Employee motivation (S)	Risk of mistakes (P)	+	Yes	HRM and TQM
Competence match (S)	Risk of mistakes (P)	+	Yes	Learning and QM

Table 2 - The number of effects of each construct and on each construct

	Effect of construct on others	**Effect on construct from others**
Logistics	2	13
Procedure	4	11
Structure	13	7
Technology	13	1
Total	**32**	**32**

Figure 2 shows that some constructs have a more extensive impact on the remaining constructs than others. The constructs with the widest impact are *Structure* and *Technology*. The constructs that are impacted the most are *Logistics* and *Procedure*.

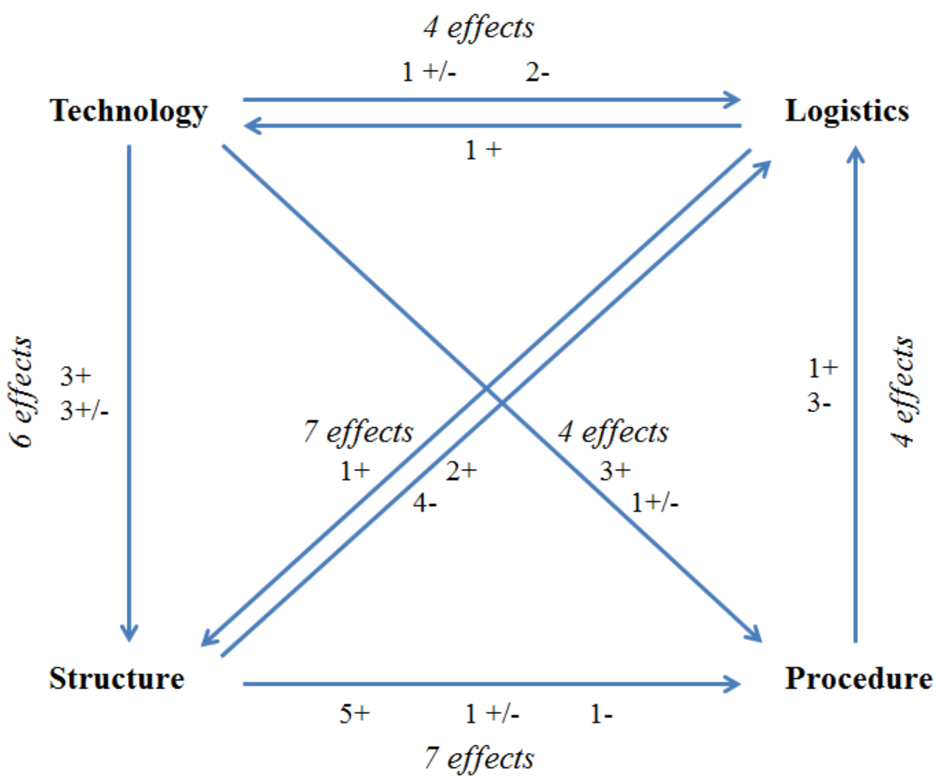

Figure 2 - Effects between each construct identified in case studies and literature

Figure 2 is a relational diagram depicting the direct effects that should be taken into consideration when implementing technologies in healthcare logistics. Three other types of relations were identified in the case studies. The first type is enablers to achieve a goal, e.g. *information management* providing knowledge about *lead time* which could then be used to identify and address challenges in the process. The second type is proactive measures to mitigate negative effects, e.g. by increasing *employee motivation* to use a technology by taking into consideration the technology's *ease of use*. The third type is trade-offs, e.g. the willingness to *increase lead time* in order to improve *output quality*. The three types of relations are not direct effects but are means to increase efficiency and effectiveness. Therefore, they are not included in this paper.

Discussion

The impact of each construct as well as impact on each construct is summarized in Table 2 and is illustrated in Figure 2. The effects between *Technology* and *Logistics* as well as *Structure* and *Logistics* lead both ways, whereas all other relations are one directional. *Structure* and *Technology* seem to have the most impact on other constructs whereas *Logistics* and *Procedure* appear to be the constructs that are affected the most by other constructs. The most extensive impacts of one construct on another are the impacts of *Structure* on *Procedure* (7 effects), *Structure* on *Logistics* (6 effects), and *Technology* on *Structure* (6 effects).

It is perhaps not surprising that *Technology* has a significant impact on the other constructs as implementing a new technology is expected to cause changes in a system. It is also to be expected that logistical aspects such as lead time will be substantially affected when changes are made to the other constructs. Re-designing a process usually leads to changes in the organizational structure. Within Business Process Reengineering, organizations are structured in process teams around outcomes (Hammer and Champy, 1993) and for Lean processes, the organization is structured in multifunctional teams (Karlsson and Åhlström, 1996). It is therefore surprising that *Structure* has such a significant effect on other constructs whereas *Procedure* is widely affected by others. *Procedure* would have been expected to have the most effect on other constructs whereas *Structure* would have been expected to be affected by other constructs.

The *Structure* indicators also reflect some *Procedure* aspects. E.g. for every competence shift, i.e. handover between employees, there is also a new process step. This could help explain why the current study suggests such large impact from *Structure* rather than *Procedure*. Therefore, findings are highly dependent on how the indicators have been defined and categorized according to *Logistics*, *Technology*, *Procedure* and *Structure*. In addition, the identified effects focus on specific indicators and the relations between them. Effects that do not include the identified indicators are therefore not included in the results. This does not mean that changes to a process do not affect the organizational structure, because they do. However, the impact of *Structure* is of greater significance to the decision process of re-designing processes and implementing technology in healthcare logistics.

Authors such as Leavitt as well as Hammer and Champy touch upon the interdependencies between constructs that are similar to *Logistics*, *Technology*, *Procedure* and *Structure*. According to Leavitt, there is a high interdependency between structure, tasks, technology and people in an organization, and any changes to one of the elements would result in changes in the other elements. Different strategies were suggested to cope with these changes (Leavitt, 2013). These interdependencies agree with findings in this study where logistics is an added construct. According to Hammer and Champy, “reengineering a company’s business processes changes practically everything about the company, because all these aspects – people, jobs, managers and values – are linked together.” They also argue that technology enables process reengineering and enables employees to make faster decisions through IT systems (Hammer and Champy, 1993). Thus, changing *Processes* affects the *Structure* in the organization and *Technology* affects *Procedures* and *Structure*. The effects of technology match those found in this study. However, the effect of reengineering business processes on organizational structure is reversed in this study. This is due to the focus on particular relations between certain aspects of *Structure* and *Procedure* in this study as well as the specific context of healthcare logistics.

A mutual relationship seems to exist between people and technology (Leonard-barton, 1988). However, the impact of people on technology is not included in this study as adapting the technology to the user is a choice and not a direct effect.

As discussed, some of the findings in this paper agree with existing literature whereas some of the findings contribute with new knowledge in the context of re-designing processes within healthcare logistics. The contribution is focused on the effects that should be considered in the decision process of re-designing processes within healthcare logistics. The effects between the four constructs *Logistics, Technology, Procedure* and *Structure* were identified by answering the three sub questions relating to the overall research question.

Conclusion

A relational diagram has been developed identifying the relations between *Logistics, Technology, Structure* and *Procedure*. The identified relations should be considered when re-designing healthcare logistics processes by implementing technologies. Relations between the constructs *Logistics, Technology, Structure* and *Procedure* have been identified based on the relations between the underlying indicators for each construct.

This study has shown that *Structure* and *Technology* have the most impact on other constructs, whereas *Logistics* and *Procedure* are affected the most by other constructs. The indicators related to *Procedure* do not seem to affect the indicators related to *Structure*. The conclusion is not that *Procedure* does not have an impact on *Structure*, because it does. However, in the context of re-designing logistical healthcare processes by implementing new technologies, the impact of *Procedure* on *Structure* should not be the focus of the decision process.

Each identified effect has been categorized as a negative or positive effect from an efficiency and effectiveness perspective. E.g. if the relation between two indicators comprises an effect on an efficiency indicator, the effect is negative if efficiency is impeded and positive if efficiency is improved. Some effects have the probability of turning out either negative or positive. The identified relations and the nature of the effects, i.e. positive or negative, can be used in a decision process for re-designing processes within healthcare logistics. This knowledge enables decision makers to take into account the effects of making changes.

Limitations and future research

This study includes effects that were evident in the bed logistics case or that were supported by literature. The framework needs to be validated by investigating other logistical healthcare processes. Findings in this paper have been based on qualitative data and literature and the results should be further validated through quantitative data analysis or simulation.

The identified relations are limited to the decision indicators for implementing technology in a logistical healthcare process. Thus, the list of effects between *Logistics, Technology, Structure* and *Procedure* seen in Table 1 is not exhaustive. Some relations were identified in the case study that did not relate to the indicators. E.g. the choice of technology will most likely result in changes in the procedure. Furthermore, changes to a procedure will lead to changes in roles and responsibilities in the organizational structure as well as to the number of competence shifts. These relations exist but are excluded from the study to limit focus to the most important indicators in a decision process of re-designing healthcare logistics.

Some of the identified effects are desirable whereas others are not. Some trade-offs were identified in the case studies that the managers were willing to make. These trade-offs were briefly touched upon in this paper. Future research should consider how to address the less desirable effects and take into account which of the less desirable effects could be trade-offs that managers are willing to make. A framework should be developed to function as a proactive decision tool addressing negative effects.

The economic aspect of implementing new technology is not considered in this study. Findings in this study can be used to identify important effects of implementing a new technology in logistical healthcare processes. When analyzing potential scenarios for process re-design, the analysis should be supplemented by a financial analysis.

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PAPER 6

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Measuring process performance within healthcare logistics
- a decision tool for selecting measuring technologies

Abstract:

90. Performance Management in Healthcare Organizations

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Measuring process performance within healthcare logistics

- a decision tool for selecting measuring technologies

Abstract

Performance measurement can support the organization in improving the efficiency and effectiveness of logistical healthcare processes. Selecting the most suitable technologies is important to ensure data validity. A case study of the hospital cleaning process at a public Danish hospital was conducted. Monitoring tasks and ascertaining quality of work is difficult in such a process. Based on principal-agent theory, a set of decision indicator has been developed, and a decision framework for assessing technologies to enable performance measurement has been proposed.

Keywords: Performance measurement, technology assessment, healthcare logistics

Introduction

Logistical processes are essential for a hospital to function and in providing services for the patients. Improving the efficiency and effectiveness of healthcare processes not only economizes on resources but also improves the quality of services. Performance measurement can support an organization to motivate employees and induce learning to improve processes (Neely et al., 2005). In a healthcare logistics context, employees will often perform tasks in various parts of a hospital and without close supervision. From a principal-agent point of view, there is a need to measure and monitor the process (Eisenhardt, 1989a; Melnyk et al., 2004). Technologies such as RFID, barcodes and portable job agents can capture data in a process and enable process measurement (Ferrer et al., 2010; Sarac et al., 2010). When measuring several performance indicators, one technology may not fit all, and a range of different technologies may be needed to enable performance measurement. Selecting the appropriate technologies for capturing data is important to ensure data validity and enable measurement of the most suitable performance indicators. Based on a hospital cleaning case study, a framework is developed that serves as a decision tool for assessing which technologies to implement to enable performance measurement in a healthcare logistics context.

Methodology

In this section, the research objectives, research design, collection of data, data analysis, and research quality are described for the study.

Objectives

A framework is developed by answering the following research questions (RQs):

RQ1: How can performance indicators measure process performance of a logistical healthcare process?

RQ2: How can technologies for measuring process performance be assessed for a logistical healthcare process?

The objective is to develop a decision support tool for logistics management within healthcare to decide on which technologies to implement for measuring process performance. *RQ1* is answered by developing a set of performance indicators that reflects the performance of the hospital cleaning process. These indicators are based on the strategic goals of the organization. To answer *RQ2*, the selected performance indicators are then used to develop a framework for assessing and selecting technologies to measure these performance indicators.

Research design and data collection

The research design chosen for this study is a single case study because it provides an in-depth understanding of a problem and is well suited for answering "how" questions (Eisenhardt, 1989b; Yin, 1994). A case study focusing on the hospital cleaning process was conducted at a public Danish hospital. Although cleaning at a hospital is not considered a traditional logistical process, the process contains some logistical elements. First, the service of cleaning is *distributed* across the hospital. Secondly, the technologies investigated are technologies commonly used within *supply chain management* and *logistics*, such as RFID and barcodes (Ramanathan et al., 2014).

Data for the hospital cleaning case was collected over a five month period from October 2014 to February 2015. During the case study, 20 interviews were carried out, the cleaning process was observed, and several documents were collected. Interviews were carried out with managers and supervisors of the logistics and cleaning departments as well as managers from the central IT department and the Strategy department. Case study results were presented to management for respondent validation (Bryman, 2012).

Analysis

A framework was developed by Jørgensen (Jørgensen, 2013) to serve as a decision support tool for assessing technologies in logistical healthcare processes. A modified version of the framework can be seen in Figure 1. The framework depicted in Figure 1 is valid for technologies performing logistical processes and will in this study be generalized for technologies capturing data to measure performance.

A principal-agent problem occurs when a) goals differ between the principal and agent and b) information and verification of behavior is difficult (Eisenhardt, 1989a). Cleaning personnel disperse into all parts of the hospital to clean their designated areas, and it is currently not possible to monitor and check the work of all employees. Providing information through performance measurement could create transparency about employee performance and the quality of their work (Neely et al., 2005). However, if data is not captured automatically, the employee may forget or deliberately neglect the registration of data. Thus, the technology used to capture data in a process affects data validity due to the particular process for capturing data. The principal-agent problem appears to be twofold: 1) getting employees to perform cleaning tasks and 2) ensuring that employees measure the cleaning process. Principal-agent theory was used to assess how the different technologies affect data validity. Based on an analysis of the hospital cleaning case using principal-agent theory, a decision process for selecting the technologies to measure performance was developed.

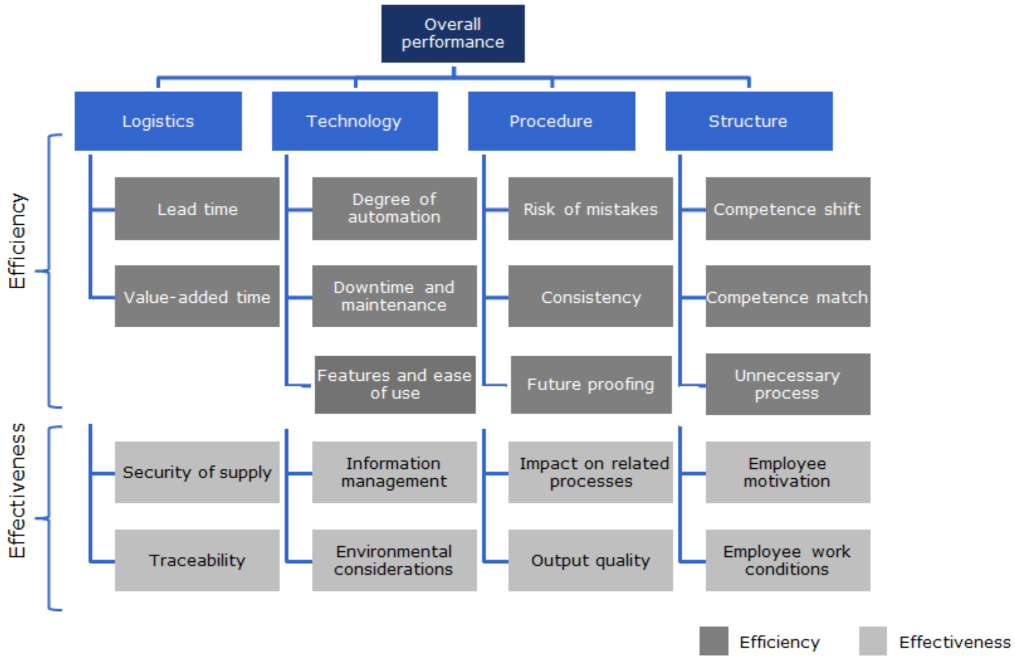

Figure 1 - Decision indicators for assessing technologies in healthcare logistics

Validity and reliability

Data from different sources were gathered and analyzed, and respondent validation was carried out to ensure construct validity (Bryman, 2012). Internal validity was ensured through pattern matching by comparing findings of this study with similar findings from a different context, in this case the framework in Figure 1 (Denzin and Lincoln, 1994; Eisenhardt, 1989b). External validity is limited to a logistical healthcare context within Denmark. This study is a generalization of an existing framework to include measuring technologies. Reliability was ensured through triangulation and colleague review.

Defining the performance indicators

Performance indicators should reflect the strategy of the organization and help achieve organizational goals (Brewer and Speh, 2000). To align organizational behavior with strategic goals, central management had in the case defined the following five performance aspects to be measured: 1) quality 2) resources, 3) productivity, 4) satisfaction, and 5) service delivery. Performance indicators were then defined for three management levels as seen in Figure 2. Investing in technologies would be necessary to enable data registration for measuring *productivity* and *delivery*. The following technologies were assessed: iBeacon, tablet, RFID, barcode and mobile job agents.

In measuring performance of the hospital cleaning process, it is only possible to check the quality of a random sample of rooms. To provide some reassurance of quality for the rooms not checked, supporting performance measures were developed. The productivity measures in Figure 2 aim to support the quality measures. Case study interviews showed that quality and time spent on cleaning are closely related. Demonstrating that a certain amount of time has been spent in a room could therefore provide supporting evidence of the level of quality provided. In line with principal-agent theory, this is an attempt to monitor the employee. It is important to note that measuring is also done to ensure that employees are allowed enough time for tasks.

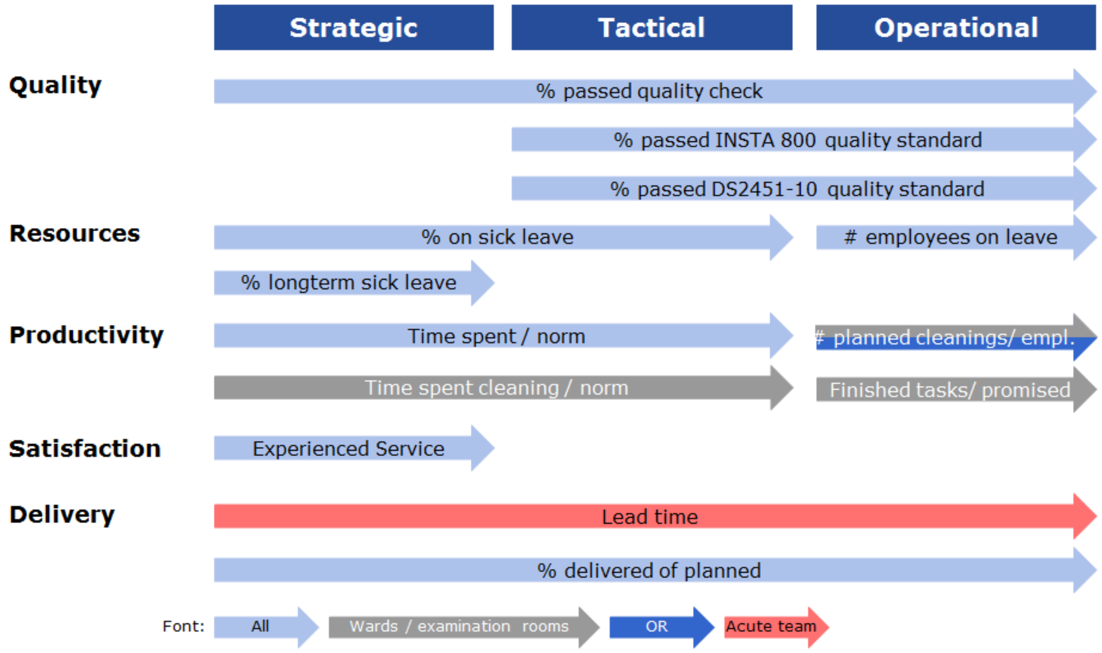

Figure 2 – Selected performance indicators across three managerial levels

Decision process for selecting measuring technologies

Some key steps were identified in the hospital cleaning process. First, a high number of data registrations, i.e. critical mass, is a precondition for a business case to justify an investment in technology. Secondly, when capturing data, some data points would be captured simultaneously in the cleaning process. E.g. the number of rooms cleaned/entered would be measured at the same point in time as starting time or end time of cleaning a room. Data points should therefore be bundled according to when data is captured in the process. Thirdly, technologies may provide the opportunity to potentially improve employee performance and the quality of cleaning; iBeacons and iPads allow for showing pictures and other types of instructions to cleaning personnel.

Data validity was assessed for every data point in combination with each of the five measuring technologies. The process of registering data was analyzed for each of the five technologies from a principal-agent and risk perspective. The following variables were found to affect data validity: 1) number of registrations, 2) level of automation for registering data, 3) employee motivation for performing registrations, and 4) traceability. Thus, the technology capturing a data point affects the validity of that data. The number of registrations and level of automation are closely related to employee motivation to perform the registration. The employee may not want to make personal performance transparent. Furthermore, the employee may forget to actively register e.g. start and end time of a task. The more registrations needed, the more the employee might forget or deliberately neglect to perform the registration. To increase validity of data, a high level of automation coupled with traceability is preferable. Number of registrations and employee motivation will not affect data validity if the data registration process is fully automated and traceable. Traceability is closely related to the principal-agent problem. Ascertaining the location of the employee will ensure that the employee was present at a given point in time. After assessing the validity of data points for each technology, it was clear that for some data points, only one technology could provide sufficiently valid data. Thus, the technologies were a given for these data points. Consequently, data points bundled with these data points were also a given. For the remaining data points to be measured, data validity should be compared to the cost of measuring data. There are several cost aspects of capturing data and measuring performance. First, there is the investment in and maintenance of technologies. Secondly, there is a cost of processing and maintaining data. Thirdly, a cost occurs if the employee spends time registering data in the process. E.g. registering entry and exit from a room is automatic with RFID, but barcodes require the employee to actively scan the barcode. Lastly, economies of scale can reduce the marginal costs.

Technologies providing the most valid data may not be economically feasible solutions for the organization. The main part of Danish healthcare is public, and funds are limited. This means that funding for logistical investments is often scarce as clinical investments are prioritized. Financial considerations could have practical implications for the choice of performance indicators and measuring technologies. Although performance measures should be governed by the overall strategy of the organization (Brewer and Speh, 2000), the economically feasible technologies may not enable measurement of the preferred measures. Therefore, two additional steps in the decision process are added to accommodate any financial limitations. Based on the analysis presented in this section, a decision process is proposed in Table 1. Decision indicators from Figure 1 that are relevant to the proposed decision steps are included in the table. All decision indicators in Figure 1 were found to be relevant except *environmental considerations*.

Table 1 - proposed decision steps and relevant decision indicators to assess technologies

Decision step	**Decision indicators affecting decision step**
1. Select performance indicators	Lead time, value-added time, security of supply, traceability, output quality, consistency, information management, competence match, unnecessary process
2. Ascertain critical mass for data registration	
3. Bundle data points	
4. Assess data validity for data-technology combinations	Risk of mistakes, consistency, output quality, degree of automation, employee motivation, employee work conditions
5. Decide to include or reject any quality bonus option	Output quality
6. Determine given technologies	
7. Determine given technologies as a consequence of bundling	
8. Compare data validity with cost of measuring to select technologies for remaining data points	Future proofing, impact on related processes, downtime and maintenance, features and ease of use, unnecessary process
9. Determine feasible technological solutions from a financial perspective	Future proofing, impact on related processes, downtime and maintenance, features and ease of use, unnecessary process
10. Adjust performance indicators if necessary	

Discussion

Measuring performance is an incentive in itself to motivate desired agent behavior (Melnyk et al., 2004). The proposed productivity measures do not ensure that the employees actually carry out the cleaning task sufficiently, but they do ensure that the person was there when the registration was made. Similarly, knowing how much time was spent in a room does not ensure that time was spent cleaning or even that it was done adequately. Thus, the principal-agent problem is still there, but it is reduced. The other principal-agent problem addressed was that of measuring data. If the process of registering data is not automated, the lack of data will show if the employee did not register data, which could itself provide an incentive for data registration. However, automating and tracing data registration will eliminate the problem entirely.

Environmental considerations were not included in the suggested decision process, but it could be taken into consideration if possible and if of significance to the organization. However, it was not relevant in this case. The financial considerations included in the decision process are deliberately included towards the end of the process to prevent innovative ideas from being discarded early in the process.

The research questions are answered by analyzing how performance measures can be developed for a process where employees are not monitored and where the level of quality is difficult to ascertain. Furthermore, a decision tool consisting of 10 steps was proposed based on an analysis of the process for registering data.

Limitations and future research

Findings in this paper are limited to a healthcare logistics context and should be validated for other contexts and settings outside of Denmark. Financial considerations provided some practical implications for the choice of performance measures. Other practical implications for deciding on performance measures and measuring technologies should be investigated.

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PAPER 7

Title:	Using the Analytic Network Process (ANP) to assess the distribution of pharmaceuticals in hospitals – a comparative case study of a Danish and American hospital
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Using the Analytic Network Process (ANP) to assess the distribution of pharmaceuticals in hospitals – a comparative case study of a Danish and American hospital

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Abstract

Pharmaceuticals are a vital part of patient treatment and the timely delivery of pharmaceuticals to patients is therefore important. Hospitals are complex systems that provide a challenging environment for decision making. Implementing process changes and technologies to improve the pharmaceutical distribution process can therefore be a complex and challenging undertaking. A comparative case study was conducted benchmarking the pharmaceutical distribution process at a Danish and US hospital to identify best practices. Using the ANP method, taking tangible and intangible aspects into consideration, the most suitable solution for pharmaceutical distribution reflecting management preferences was identified.

Keywords: Hospital logistics, Pharmaceutical distribution, Analytic Network Process

Introduction

Healthcare expenditure is growing year on year and hospitals face an increasing pressure to provide high quality care at lower costs. Pharmaceutical products have become more expensive and amount to almost 20% of health spending in OECD countries (OECD, 2015). Hospitals deal with high inventory levels and storage costs. Reducing pharmaceutical handling and logistics costs can therefore lead to major cost savings (Pinna et al., 2015).

Timely delivery of the correct pharmaceuticals to the right patients is vital for patient care. However, little empirical evidence exists on the opportunities for improving internal pharmaceutical logistics in a hospital (Romero and Lefebvre, 2015). Process design and various technological solutions can enhance the precision and timeliness in the delivery of pharmaceuticals, while at the same time reducing handling costs. Just in Time (JIT) can reduce inventory levels and handling costs in a hospital (Aptel and Pourjalali, 2001). Track and trace throughout a process can help eliminate waste by providing information that enables planning, coordination, and mistake prevention in processes. Barcodes and RFID can be used to track and trace pharmaceuticals (Anand and Wamba, 2013). Automated guided vehicles (AGVs) and pneumatic tube systems are examples of technologies that can be used for transportation and delivery of various types of goods in hospitals, e.g. (Granlund and Wiktorsson, 2013).

Hospitals are complex systems (Lillrank and Liukko, 2004), and implementing a new technology in a process has implications for procedures and organizational units across a hospital e.g. (Romero and Lefebvre, 2015). Moreover, the improvements achieved by implementing a particular technology in one organization might not be the same for another due to different conditions for operating and a different technological base (Chan et al., 2001). Recognizing the effects of changing a process and implementing new technologies is important in order to make an informed decision. A simulation model is a way to assess the effects over time of various scenarios and is useful for improving process flows and determining the need for resources, e.g. (Jun et al., 1999; Zhu et al., 2012). Thus, simulation models do not consider intangible aspects unless they affect the behavior of the process. An analytic approach to assessing process designs and technologies can capture the complexities and implications of a decision (Chan et al., 2001; Meredith and Suresh, 1986). The Analytic Network Process (ANP) and Analytic Hierarchy Process (AHP) are multi-criteria decision analysis methods that can rank solutions based on a set of parameters (Saaty, 2004). AHP and ANP allow for a quantitative comparison of solutions based on qualitative and quantitative criteria, whilst ensuring transparency of the decision process. Both methods have previously been applied in healthcare settings (Liberatore and Nydick, 2008) and to assess logistics processes (Meade and Sarkis, 1998) and technologies (Ordoobadi, 2012). The ANP method was chosen over the AHP method, as ANP accounts for interdependencies between parameters (Saaty, 2004). The following research question is addressed in this paper: *How can ANP be applied to assess process designs in healthcare logistics, exemplified by pharmaceutical distribution in hospitals?*

Methodology

Objectives and research design

This study aims to provide a method for how ANP can be applied in a benchmarking effort to select a process and technology solution that best fits the preferences of decision makers in a hospital. The pharmaceutical distribution process is compared at a Danish and US hospital. As part of the benchmarking study, best practices were identified for the US hospital and the applicability for the Danish hospital was assessed.

A case study was chosen as research design because it enables in-depth understanding of a phenomenon (Yin, 1994), in this case the pharmaceutical distribution process. Furthermore, case studies are suitable for building theory within the field of operations management (Meredith, 1998; Voss et al., 2002), making the research design suitable for this study. Two case studies of the pharmaceutical distribution process were carried out; one at a major public Danish hospital and another at a major nonprofit, top-ranking US hospital. The applicability of the US pharmaceutical distribution process design to a Danish hospital was investigated by comparing the process and organization of the two hospitals.

Data collection

The collected data was both qualitative and quantitative in nature. Data was collected through semi-structured interviews, structured interviews, and direct observations at the Danish and US hospital. Furthermore, quantitative data pertaining to management preferences for evaluated solutions was obtained for the Danish case study. Data for the

Danish case study was collected from February to August 2015 based on seven semi-structured and one structured interview, and process observations on four occasions. Data was collected for the US pharmaceutical distribution case study from September 2015 to January 2016 through process observations on three occasions and six semi-structured interviews. Interviewees were selected based on their knowledge of and involvement in the pharmaceutical distribution process, including key decision makers. Observations were recorded for each step of the pharmaceutical distribution process. The interviews lasted between ½-1½ hour and the observations lasted between ½-1 hour.

Analysis

A gap analysis was conducted as part of the benchmarking study (Camp, 1995). The pharmaceutical process was compared for the two hospitals and gaps between process steps were identified. Best practices identified in the gap analysis were subsequently evaluated for the Danish hospital using the ANP method. In the ANP method, logistics management at the Danish hospital subjectively assessed a set of decision criteria for each alternative. The decision criteria used for evaluating the alternatives are depicted in Figure 1. The software Super Decisions (www.superdecisions.com, 2016) was used to calculate the ANP ranking of solutions and identify the most desirable solution for the Danish hospital.

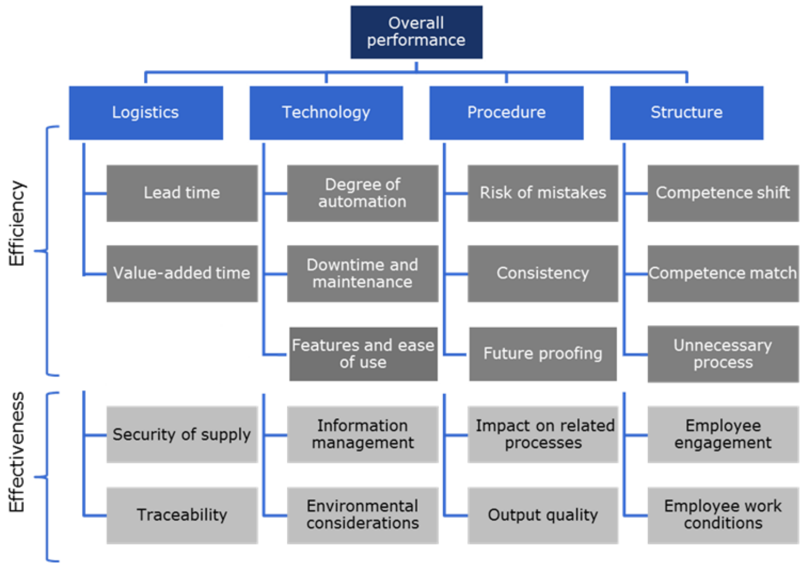

Figure 1 - Decision criteria for assessing process designs in healthcare logistics

The decision criteria in Figure 1 were identified in a previous case study of the bed logistics process in five Danish hospitals (Feibert and Jacobsen, 2015). The developed framework consists of 19 decision criteria for assessing technologies and process designs in healthcare logistics. The identification of decision criteria was based on two analyses: 1) challenges in the process, 2) reasons for implementing process changes and technologies. The identified decision criteria each relate to one of the following constructs: 1) Logistics, 2) Technology, 3) Procedure, and 4) Structure. Furthermore, the decision criteria are divided into efficiency and effectiveness to reflect both aspects of performance (Mentzer and Konrad, 1991; Neely et al., 2005). The decision criteria in Figure 1 and relations between the decision criteria were identified for the bed logistics case study and were validated for the pharmaceutical distribution cases.

Validity and reliability

Different types of data sources were utilized to triangulate the findings and ensure reliability and internal validity. E.g. interviews were conducted with several interviewees from the same department and from different parts of the supply chain. Furthermore, the decision criteria from the previous study were validated through the interviews and respondent validation further strengthened internal validity.

The external validity of the study was ensured through case study sampling. The Danish hospital was chosen because it is the same hospital as from the previous study (Feibert and Jacobsen, 2015). The US hospital was chosen because it is a top ranking hospital and could potentially provide best practices for the Danish hospital. The hospital sampling allowed for the decision criteria to be generalized to other hospital logistics processes such as the pharmaceutical distribution process and to other contexts such as a US hospital.

Literature review

Literature on how to improve internal logistics of pharmaceuticals is limited (Romero and Lefebvre, 2015). Al-Shaqha and Zairi investigated the reengineering of pharmaceutical processes and found that decentralizing pharmacists to the clinical departments provides more patient-focused care (Al-Shaqha and Zairi, 2000). Pinna and colleagues found that a unit dose pharmaceutical distribution system entails a more simple process with reductions in stock levels and easier stock management (Pinna et al., 2015). Chen and colleagues found that the implementation of TQM tools in a pharmaceutical logistics organization led to cost reductions, increased sales and low employee turnover (Chen et al., 2004).

Technologies can play a vital role in reengineering processes (Hammer and Champy, 1993; Hammer, 1990). One of the technologies that have caught much attention in logistics literature, including hospital logistics, is radio frequency identification (RFID), e.g. (Chircu et al., 2014; Romero and Lefebvre, 2015; Wamba and Ngai, 2015; Wamba et al., 2013). Wamba and colleagues identified three applications of RFID technology in healthcare: asset management, patient management and staff management (Wamba et al., 2013). Chircu and colleagues investigated a pharmaceutical supply chain end-to-end and identified the different benefits of RFID for each actor in the supply chain. The benefits identified include time and money savings, safety of medication, easier control and transport of medication, reductions in delivery errors, compliance on temperature, better documentation, reductions in manual data entry costs, easier information transfer, and user-friendly track and trace of drugs (Chircu et al., 2014). RFID is often compared to the more established barcode technology for track and trace purposes. E.g. Romero and Lefebvre identified some benefits of using RFID, barcodes and the two technologies in conjunction. RFID provided the most benefits, e.g. efficiency and accuracy, inventory visibility and reduced inventory costs, increased patient security and shorter cycle times (Romero and Lefebvre, 2015). Çakici and colleagues compared inventory costs when using RFID and barcodes and found that cost savings are significantly larger using RFID than barcodes, especially when combined with business process reengineering. However, RFID technology is more costly to install and is not without errors (Çakici et al., 2011; Romero and Lefebvre, 2015).

Poor inventory management can lead to high inventory costs and stock-outs. Inventory control approaches such as JIT, stockless and vendor managed inventory (VMI) can improve the efficiency and effectiveness of materials handling. Kim and Schniederjans found that JIT and stockless systems can reduce inventory costs and improve service quality (Kim and Schniederjans, 1993). However, JIT solutions require close proximity between wholesaler and clinic, which is not always possible. A case study of a pharmaceutical supply chain in Malaysia therefore found that VMI was a more suitable solution that could reduce the amount of high-cost urgent orders and improve stock availability (Mustaffa and Potter, 2009).

Böhme and colleagues conducted a benchmarking study on improving the reliability of medical supply value streams. Identified best practices included visual management, pharmaceutical dispensing machines, barcoding of consumables, and automatically adjusted stock levels (Böhme et al., 2016). Benchmarking is a way to systematically search for industry best practices that can lead to superior performance (Camp, 1989a). Benchmarking consists of a metric component and practice component (Camp, 1989b; Voss et al., 1997); however, a benchmarking study does not necessarily include both (Hanman, 1997; Mayle et al., 2002). One of the steps in a ten step benchmarking process defined by Camp is performing a gap analysis. The most common gap analysis is analyzing the financial gap. A more process oriented gap analysis utilizes tools such as flow charts to identify differences in processes and subsequently differences in performance. Based on a gap analysis, best practices can be identified for the investigated processes in order to achieve or exceed performance levels of the superior process (Camp, 1995).

One of the dilemmas in benchmarking is displaying multiple measures when comparing processes (Chan et al., 2001; Meredith and Suresh, 1986). Analytic methods such as AHP can be used to justify technologies (Chan et al., 2001; Meredith and Suresh, 1986) and to prioritize key benchmarking activities (Camp, 1995). The methods are largely quantitative but can include intangible benefits to better capture the complexities in a system (Chan et al., 2001; Meredith and Suresh, 1986).

Hospital comparison and identification of process gaps

The Danish hospital is a 700 bed public hospital in the capital region of Denmark. Pharmaceuticals are received in the docking area from a regional warehouse and transported in carts to an area where boxes containing pharmaceuticals are re-arranged according to the recipient. The boxes are then distributed on carts to the receiving clinical departments where the pharmaceutical items are stored. It is not possible to track the items anywhere in the process, and received pharmaceuticals are not checked with the order until they are unpacked and stored in the clinical departments. When the pharmaceuticals are administered to the patients, barcodes are used to ensure the right drug for the right patient.

The US hospital is a 1,250 bed non-profit hospital ranked as one of the best hospitals in the US. Pharmaceuticals are received in a docking area and transported to the inpatient pharmacy manually or by AGVs. Received items are then checked with orders and transported to the storage area. Throughout the day, pharmaceutical products are picked and delivered manually or through pneumatic tube systems to the clinical departments. In the clinical departments, items are stored in dispensing stations before being administered to patients. At each handover in the process, items are scanned using barcodes, enabling track and trace of items throughout the process and ensuring that the correct items are handed over.

The main gap between the Danish and US process is that items can be tracked throughout the US process using barcodes. Track and trace in the US process allows for better monitoring of the process. At any point in time, the location of all items is known due to the barcoding system. Conversely, in the Danish process, items are unaccounted for until they are received in the clinical departments. The only documentation that occurs is the registration of number of carts and boxes received in the docking area.

Furthermore, the US process is more automated as AGVs and pneumatic tube systems are used for some transports. However, most items are still transported to the clinical departments manually.

Another significant difference is the placement of inventories in the process. At the US hospital, there is a central inventory serving the decentralized inventories in each clinical department. Most pharmaceuticals are reordered based on a reorder point in the central pharmacy. In the Danish hospital, inventories are only found in the clinical departments where a third party provider manages the inventories.

The comparison of the Danish and US processes identifies some process design gaps, suggesting a more advanced pharmaceutical distribution process in the US. The following three aspects of the US process design were evaluated for the Danish hospital:

- AGV
- Pneumatic tube
- Track and trace

Track and trace would be an inherent part of the AGV and pneumatic tube solutions but can also be viewed as a solution in itself. The three solutions are applicable to the Danish hospital because they are already part of the future plan for the hospital or have been tested for possible future use. Firstly, AGVs are already planned as part of the future Danish hospital, which is undergoing a significant expansion. Secondly, a pneumatic tube system already exists between the emergency department and the lab, albeit on a small scale. Finally, an RFID solution has been tested for pharmaceuticals and other items, but the project was stopped for political reasons. Furthermore, an RFID solution would address the lack of control in the pharmaceutical distribution process. The three solutions are therefore viable for the Danish hospital.

Despite a more advanced pharmaceutical distribution process in the US, the process still poses some issues. E.g. errors occur even with the use of barcodes to track the pharmaceutical products. This issue is mainly due to human errors when overriding the system, leading to another issue of stock counting accuracy. Most of the stock is automatically reordered when the stock level reaches a reorder point. The stock count is based on barcode registrations but must be manually counted every two weeks to ensure that the stock count matches the system records. As the manager of the pharmacy points out, this task would not be necessary if RFID were used instead, see also e.g. (Çakici et al., 2011).

Results from the ANP analysis to evaluate pharmaceutical distribution solutions

Three solutions were assessed for the pharmaceutical distribution process at the Danish hospital. These scenarios were inspired by the gap analysis of the Danish and US processes and include the following: 1) AGV, 2) pneumatic tube, and 3) track and trace.

(1) AGV. In the AGV solution, AGVs transport pharmaceuticals around the hospital. Unless the pharmaceutical products are delivered, sorted according to clinical department on carts manageable by AGVs and tagged with an RFID, some manual handling will have to take place to load the AGVs. Upon arrival in the departments, staff will have to receive the load or the AGV will place the load in a designated area. Narcotics pose an additional issue as they cannot be transported unaccompanied. At the US hospital, this issue was addressed by having an employee follow the AGV. The US hospital experienced fewer injuries after having implemented AGVs because of less heavy lifting and pushing of carts. Another benefit of AGVs was that they could be used

for transporting several different types of materials throughout the hospital at any hours of the day.

(2) Pneumatic tube. A pneumatic tube system can transport canisters through a network of tubes using compressed air. A main pharmaceutical inventory would hold most of the inventory and smaller inventories would be held in the clinical departments. This would lead to an overall smaller inventory as the buffer inventories currently held in each clinical department would be reduced to a smaller buffer in the central inventory. Larger orders to the clinical departments might still be transported manually to the reduced decentral inventories, but the majority of non acute medicine would be transported via pneumatic tubes. One of the advantages of pneumatic tubes is the reduced risk of theft during transport compared to the exposed transport with AGVs.

(3) Track and trace. The track and trace solution could be implemented as a separate solution or in conjunction with the AGV or pneumatic tube solutions. RFID or barcodes can be used to track and trace items through a supply chain. This would ensure knowledge about the location of a particular item at any point in time and ensure better process control.

The ANP method was applied to the decision criteria in Figure 1 to provide a quantitative assessment ranking the three alternatives for the pharmaceutical distribution process at the Danish case study hospital. The results of the ANP analysis for the Danish hospital are seen in Table 1. The “Raw data” column contains output from the ANP analysis, the “Normals” column contains normalized output data, and the “Ideals” column contains data with the ideal solution receiving the value 1. The results showed that the most desirable alternative for the Danish hospital is a pure track and trace solution.

Table 1 - synthesized priorities for solutions

Scenario	**Raw data**	**Normals**	**Ideals**	**Rank**
AGV	0.18	0.24	0.58	3
Pneumatic tube	0.25	0.33	0.79	2
Track & trace	0.32	0.42	1.00	1

Discussion

The study found that the decision criteria in Figure 1 can be used in combination with the ANP method to assess process solutions and technologies in a healthcare logistics context. Applying the ANP method to the decision criteria provides a more data driven and transparent decision process, taking intangible aspects and the preferences of decision makers into account. Furthermore, the study provides an example of how ANP can be used as part of a benchmarking effort in selecting a best practice solution that best fits the preferences at a particular hospital. Each of the assessed scenarios had initially been presented and discussed with the logistics manager at the Danish hospital. The interviews indicated a preference for the track and trace solution, which was validated by the ANP analysis.

A framework with relevant decision parameters to which an analytic method such as ANP can be applied is a prerequisite that is often not in existence (Chan et al., 2001). This study found that the framework of decision criteria can be used to assess logistical processes in hospitals. Furthermore, the decision criteria and their inter-relations were validated in the study and can be generalized from the bed logistics process in a Danish hospital to the pharmaceutical distribution process in a Danish and US hospital setting.

The best practices identified by Böhme and colleagues for the medical supply process include visual management, pharmaceutical dispensing machines, barcoding, and automatic reordering of inventories (Böhme et al., 2016). All of these practices were identified at the US hospital. Based on discussions with the Danish logistics manager, barcoding and subsequently the more sophisticated RFID technology were chosen as potential scenarios. Furthermore, pneumatic tube systems and AGVs were identified as significant potential improvement initiatives, which had also been identified in healthcare logistics literature, e.g. (Granlund and Wiktorsson, 2013; Jørgensen et al., 2013; Landry and Philippe, 2004).

Both RFID and barcodes would enable track and trace of the pharmaceutical items in the distribution process. RFID would provide more benefits than a barcode solution, but an RFID solution is also a more costly solution (Romero and Lefebvre, 2015). Current trends and potential benefits are proponents of RFID technology. However, the issue of financing is one of the inhibitors of RFID adoption (Wamba et al., 2013). The Danish hospital is a public hospital and subject to strict financial budgets that rarely allow for investments in logistical opportunities. Given that the Danish hospital already has the software needed to use barcodes and the solution being the least expensive option, barcodes might be the most plausible option. Another decision factor to consider is the impact and influence of the rest of the supply chain. E.g. the rest of the supply chain using barcodes is another proponent of the barcode solution (Romero and Lefebvre, 2015). Hence, there is a network effect that must be considered. E.g. to reap the full benefits of introducing RFID into the supply chain would mean that RFID would also have to be implemented by actors upstream in the supply chain. Similarly, the pneumatic tube solution might require a change in the format of the delivered pharmaceuticals, e.g. to unit dose packaging (Pinna et al., 2015), not only to that hospital but all hospitals supplied by the same wholesaler.

Implementing a track and trace solution provides the much needed information of the whereabouts of pharmaceutical items throughout the logistics process at the Danish hospital. Pharmaceutical supply chains are subject to stringent regulations due to the potential adverse effects on health (Shah, 2004). The diligent use of barcodes in the US hospital ensures transparency in the supply chain and control of the process (Chircu et al., 2014).

This paper contributes to the limited literature on benchmarking within healthcare logistics and provides an example of how the ANP method can be used in a benchmarking effort to rank potential process and technology solutions. Furthermore, the case study provides insights on process gaps and best practices in the pharmaceutical distribution process between a public Danish hospital and a high ranking US hospital.

Conclusion

This study successfully applied ANP for evaluating pharmaceutical distribution solutions based on a set of decision criteria specific to a healthcare logistics context. A method for assessing technologies and process designs in healthcare logistics processes has been proposed. The applied method incorporates both quantitative measures and qualitative decision criteria capturing the complexities of a healthcare setting. Best practices were identified for the US hospital and validated as viable solutions for the Danish hospital. Based on the ANP method, the most preferable solution for the Danish case study hospital was determined. Applying the study’s demonstrated approach yields a data driven decision process for a more informed decision.

Limitations and future research

The decision criteria to which the ANP method was applied have been validated for a bed logistics process and a pharmaceutical distribution process and in a Danish and US setting. The findings of this study were only tested for two Western hospitals. To improve the validity of findings, the framework should be applied to other hospital logistics processes and other settings. Furthermore, a sensitivity analysis should be conducted to assess the effects on the results from changing the importance of the parameters in the framework. Finally, more empirical research is needed on how to benchmark healthcare logistics processes, both on the metric and best practice side.

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